U.S. DEPARTMENT OF COMMERCE
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PB-259 993

Design Parameters for Animal Waste Treatment Systems Nitrogen Control

New York State Coll of Agriculture and Life Sciences, Ithaca

Prepared for

Environmental Research Lab, Athens, Ga

Sep 76

PB 259 993

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U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-600/2-76-190
September 1976

DESIGN PARAMETERS FOR ANIMAL WASTE TREATMENT SYSTEMS - NITROGEN CONTROL

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ABSTRACT

Laboratory, pilot plant and field scale studies were conducted to evaluate design parameters for treating animal wastes and achieve nitrogen control. The studies indicated that nitrogen control can be achieved in a single aeration unit. By proper manipulation of the microbial activity, nitrogen removals in the range of 30 to 90 percent of the total input nitrogen to the system could be achieved.

Depending upon the phase of operation, nitrogen losses occurring in the system were either due to ammonia volatilization or denitrification of the oxidized nitrogen compounds. Most of the nitrogen losses during the start-up phase were due to ammonia volatilization. Nitrogen losses occurring during the nitrification phase were attributed to denitrification occurring in the microbial floc due to localized anaerobic conditions in or around microbial floc.

The feasibility of achieving varying amounts of nitrogen using a sequential nitrification-denitrification mode of operation was demonstrated in a pilot plant oxidation ditch treating poultry waste.

Agronomic field studies conducted indicated that nitrogen from the oxidation ditch-stabilized poultry manure was as available to plants as nitrogen from fresh poultry manure. Nitrate concentrations in soils increased with increasing rates of manure application. At a given rate of manure application, nitrate levels in soils were higher under corn than under grasses. Grasses responded favorably to application of manurial nitrogen in the range of 100-170 Kg N/ha. There were seasonal variations in the responses of grasses and corn to manurial nitrogen. During spring, manure application rates beyond 224 Kg N/ha were not beneficial to corn and could cause damage to crops as well as the environment.

Based on experimental evidence on plant growth, corn and grasses, it was recommended (1) that in the spring season, poultry manure could be applied on either grass or corn, and (2) that the application in the fall season should be on grass.

This report was submitted in fulfillment of Project Number S800767 by Cornell University under the sponsorship of the Environmental Protection Agency. Work was completed as of December 31, 1974.

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ACKNOWLEDGEMENTS

This research was supported by the Environmental Protection Agency under project number S800767 and by the College of Agriculture and Life Sciences, Cornell University. The guidance of Mr. Lee Mulkey, Environmental Protection Agency, Athens, Georgia, who served as the project officer, is gratefully acknowledged.

The project is a multidisciplinary effort of the Departments of Agricultural Engineering and Agronomy of the College of Agriculture and Life Sciences at Cornell University. Drs. R. C. Loehr and P. J. Zwerman are the project directors.

The principal investigators associated with the project are: Drs. T.B.S. Prakasam, E.G. Srinath, T. Bateman and T. Scott.

The help of J. H. Martin, Jr., A. C. Anthonisen and H. T. Grewling, and the support of Dr. M. J. Wright, Chairman, Department of Agronomy are gratefully acknowledged. Technical assistance was provided by Y. D. Joo and R. Jones.

The help of R. J. Krizek, J. F. Gerling, and E. Callinan in the preparation of the figures is gratefully appreciated.

The patience and skill of Arlene Learn, Diane LaLonde, Sally Gray, and Judy Eastburn in typing the report are most sincerely appreciated.

SECTION I

CONCLUSIONS

1. Aerobic systems can be designed to treat animal wastes and achieve COD, solids, odor, and nitrogen control.

2. Nitrogen control can be achieved in a single aeration unit by manipulating the microbial processes of nitrification and denitrification. Such control is compatible with the normal operation of the aeration unit and the continuous addition of manure to the unit.

3. The aerobic systems can be manipulated to achieve nitrogen removal in the range of 30 to 90 percent of the total input of TKN into the system depending upon the nitrogen management objectives of the animal production unit. Various modes of operation can be used to achieve the desired objectives of nitrogen control.

4. Nitrogen losses occur in animal waste treatment systems even under aerobic conditions. Variations in the extent of nitrogen losses are related to the total oxygen demand exerted.

5. The nitrogen losses occurring under aerobic conditions are the result of either ammonia volatilization or denitrification of the oxidized nitrogen compounds depending on the phase of operation of the treatment system. Nitrogen losses due to ammonia volatilization are maximum during the

start-up-phase of a treatment system. Denitrification losses taking place during the aerobic phase are postulated as due to the localized anaerobic conditions in or around the microbial floc.

6. Using a mass balance approach, predictive relationships were developed to calculate the nitrogen losses obtainable in the aerobic systems.

7. The nitrifying microorganisms can withstand severe environmental stresses such as high concentrations of undissociated ammonia and very low concentrations of dissolved oxygen or even anaerobic conditions for long periods of time. In view of this, an aerobic animal waste stabilization unit can be operated using a cyclical nitrification-denitrification approach to achieve nitrogen control.

8. If the concentration of solids, COD and nitrogen content of the waste is known, it is possible to estimate the quantities of oxygen needed to achieve odor control and nitrogen removal. The size of treatment units and the lengths of rotor needed for operating the oxidation ditch systems can be calculated.

9. Nitrate concentrations in soils increase with increasing rates of poultry manure application. Concentrations of nitrates are about twice as high in surface soils as in subsoils for a given rate of manure application.

10. For a given rate of manure application, soil nitrate levels were higher under corn than under grass. Poultry manure applied in the spring for corn should not exceed rates that supply more than 224 kg N/ha. Rates above this level can supply more nitrates than will be taken up by corn. These excess nitrates are then subject to leaching beyond the rooting depths of corn.

11. There were no differences between fresh poultry manure or oxidation ditch mixed liquor from an oxidation unit treating poultry manure on the nitrate concentration in soils.

12. The manure source did not result in differences in runoff water, nitrates, ammonium, total soluble phosphorus or soil sediments carried off by the runoff water.

13. Corn grain yields responded significantly to poultry manure applications up to 224 kg N/ha.

14. Although it is difficult to calculate mineralization rates, estimates are that 50% of the nitrogen in poultry manure is available the first year. Much smaller amounts are available in succeeding years.

15. Grasses responded favorably to poultry manure at application rates in the range of 100-170 kg N/ha.

16. Poultry manure applied in the fall should be on grass. Spring applications can be on grass or corn.

17. Nitrogen from oxidation ditch manure was as available to plants as nitrogen from fresh manure.

SECTION II

PROJECT NEED AND OBJECTIVES

PROJECT NEED

The changes in agricultural practices, such as mechanization and animal production in close confinement significantly have increased the efficiency of such production. Such changes at the same time also have created more difficult waste management problems. The satisfactory disposal of animal wastes from these operations is the key to both successful animal production and environmental protection. The close proximity of some of these animal production units to towns, and a desire to protect the quality of water resources have resulted in a greater awareness of the environmental problems caused by manure disposal from these units.

Disposal of poultry wastes presents a particularly difficult problem. They contain high concentrations of organic matter which can easily undergo putrefactive changes. The proper management of manure is essential for the success of the poultry operations and protection of the environment. In view of the 1972 amendment to the Federal Water Pollution Control Act, controlled land disposal of wastes assumes greater importance in the schemes of waste management. Since land is the ultimate receptacle for the wastes, the extent of waste stabilization required before such disposal is not comparable to those needed in municipal sewage treatment works. A high degree of BOD or COD removal, comparable to secondary effluent quality, is not needed. The objectives of waste stabilization will be based on factors such as odor control and nutrient management.

The disposal of the wastes on land may result in subsequent runoff causing surface water pollution and contamination of groundwater due to subsurface percolation of nitrogen in the wastes. The disposal of poultry wastes on land requires the design of feasible waste stabilization systems that will minimize the risks of causing air pollution, soil contamination, and surface and groundwater pollution problems. When adequate land is available, it is desirable to utilize the manurial nitrogen for crop production and to conserve as much nitrogen as possible. In situations where integration of wastes with soil for the benefit of crop production is not possible, there is need to decrease the nitrogen content to make the stabilized waste suitable for disposal on the available land.

To devise approaches for the proper disposal of animal wastes on the land, data are needed on the stabilization required to achieve varying degrees of nitrogen removal without sacrificing other environmental protection objectives such as odor control and BOD and COD removal. Earlier studies (4, 5, 20) on animal waste management have shown that by operating an in-house oxidation ditch system, the manures could be stabilized and also render the animal confinement area almost free of odors. The studies also indicated that by "in situ" denitrification of the nitrified liquor in the oxidation ditch, the nitrogen content of the wastes could be significantly decreased. However, the available information on the methods of operation of oxidation ditch systems was not sufficient to develop guidelines to operate the oxidation ditch system to achieve different degrees of nitrogen removal. A knowledge of such modes of operation of the oxidation ditch system is essential to broaden the spectrum of alternatives available for designing acceptable animal waste management systems.

PROJECT OBJECTIVES

The specific objectives of this study were to: (a) develop design criteria to achieve nitrogen and odor control in animal waste stabilization systems; (b) demonstrate the feasibility of achieving nitrogen control by using oxidation ditches; (c) determine the rate, form and time of manure application permissible without causing pollution of surface runoff and groundwaters; and (d) determine the optimum rate, form and time of application for best crop response.

The main emphasis of the project has been to demonstrate the feasibility of achieving nitrogen control without sacrificing other environmental objectives such as odor elimination, waste stabilization, and nutrient availability for crop production. The develpoment of design criteria to achieve these objectives is important for designing and operating waste stabilization systems to meet varying waste management objectives.

SECTION III

EXPERIMENTAL STUDIES ON WASTE STABILIZATION, LAND DISPOSAL AND NITROGEN CONTROL

INTRODUCTION

Until recently agriculture was not considered a serious source of environmental pollution due to the diverse nature of agricultural activities and comparatively small size of the production units. With the changing practices in animal production, the sizes of operations are larger and have contributed to the marked increase in agricultural output. At the same time these production practices have altered the traditional complimentary relationship between livestock and crop production whereby the livestock wastes were used to fertilize and amend the croplands. There is an increasing need for the disposal of large quantities of manures produced in concentrated livestock operations. As an example of the trends in livestock industry, estimates of layer production and the nitrogen, total solids and COD content of the manures generated by egg production units are shown in Table 1.

The effluent guidelines for feedlot industry (3) indicate that the wastes should not be discharged into watercourses. Thus land disposal of animal wastes continue to be an important component of any animal waste management scheme. Due to the recent economic changes, and possible shortages of chemical fertilizers, animal wastes are being viewed with interest

Table 1. PRODUCTION OF LAYERS*AND ESTIMATES OF THE NITROGEN, TOTAL SOLIDS AND COD CONTENT OF THE MANURES FROM THE EGG PRODUCTION FACILITIES**

Year	Layers (millions)	Nitrogen (million lbs)	Total Solids (million lbs)	COD*** (million lbs)
1960	295	597.7	7115.1	3557.6
1965	301	609.8	7259.8	3629.9
1970	313	634.1	7549.2	3774.6
1980	348	705.0	8393.4	4196.7
2000	446	903.6	10757.0	5378.5

* based on references 1 and 2

** estimates based on the observations at our laboratory that the quantity of total solids and nitrogen content of the excreta is 30 and 2.5 gms per day per bird

*** COD estimates are based on the approximation that about 50% of the total solids is COD

as alternate sources of crop nutrients. When adequate agricultural land is available, it is preferable to integrate animal waste disposal with crop production and thereby take advantage of the fertilizer value of the wastes. Difficulties arise when either local conditions are not favorable, or adequate land is not available for disposal. Excessive amounts of manure on land can alter the physical properties of the soil,and the oxygen demand exerted by organic matter can influence the microflora of the soil. Uncontrolled spreading of manure on land also increases the risks of contamination of surface waters by runoff and groundwater by seepage.

The contaminants reaching the surface waters by runoff from lands on which manure is disposed include among other things, (a) organic matter;

(b) nitrogen compounds; and (c) phosphorus compounds. Phosphates present in the wastes are immobilized by reactive iron and aluminum present in the soil, and the organic matter is adsorbed on the soil particles. Nitrification of NH_4^+ occurs in soil and water environments and in aerobic treatment systems. Unlike NH_4^+, nitrites and nitrates are not retained by clay particles in the soil. The infiltration of nitrate results in contamination of groundwater. If the concentration of nitrates in the water is high, then the water is unfit for potable purposes. Oxidation of NH_4^+ in the receiving waters exerts a demand for oxygen. Therefore, the application rates of nitrogen to the land can be a controlling factor whether the land is used for either growing crops or for disposal to meet the objectives of environmental protection. These objectives include odor control, waste stabilization and nutrient management.

Unless the wastes are properly stabilized and managed, land disposal of poultry wastes, especially in situations where adequate land is not available, could lead to environmental damage. In this context, the problem of detrimental effects on the environment due to manurial nitrogen is of particular concern. The available technology for nitrogen management in animal wastes is inadequate. Therefore, the disposal of animal wastes on land presents a challenge for the environmental engineers to design feasible stabilization and disposal systems that will minimize the risks of air and water pollution.

An understanding of the effect of different factors influencing the aerobic stabilization of wastes is important to the design and operation of stabilization systems for nitrogen and odor control. Microorganisms present in the waste stabilization systems utilize the carbon, nitrogen, and phosphorus compounds for their metabolic activities. The resulting transformations account for the changes in the characteristics of the waste, especially in the total solids, COD, nitrogen and phosphorus contents. The ultimate products of oxidation of carbonaceous matter are CO_2 and water. The decreases in total solids and COD occurring in aerobic stabilization systems are due to microbial transformations resulting in release of CO_2.

Nitrogen in fresh animal excreta is essentially in the organic form as proteins, urea, or uric acid (mammals excrete urea, birds excrete uric acid). Transformations occurring in waste stabilization systems can result in different forms of nitrogen in the stabilized waste. The exact sequence of changes is influenced by environmental conditions. The first step in such changes during stabilization of animal wastes is ammonification of organic nitrogen:

$$\text{Organic nitrogen} \xrightarrow[\text{(heterotrophs)}]{\text{Ammonification}} NH_3 \rightleftharpoons NH_4^+ + OH^- \quad (1)$$

Ammonification of organic nitrogen is accompanied by an increase in pH. If the ammonium concentration and pH are sufficiently high, ammonia volatilization can occur.

Under aerobic conditions, ammonium nitrogen can be microbially oxidized to nitrate by two groups of autotrophic microorganisms, viz; Nitrosomonas and Nitrobacter. This process of oxidation of NH_4^+ to NO_3^- is termed as nitrification.

$$NH_4^+ + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O \quad (2)$$

$$NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \quad (3)$$

Under anaerobic conditions, the nitrite and nitrate can be reduced to nitrogen gas (N_2) or gaseous nitrogen oxides (N_2O or NO) by denitrifying organisms.

The rate of oxygen utilization in aerobic stabilization system can be expressed as a function of the rate of removal of organic matter and the rate of endogenous respiration of the microbial mass. The following general equation describes the rate of oxygen utilization for oxidation of carbonaceous matter:

$$\frac{do}{dt} = a \cdot \left(\frac{dF}{dt} \right) + b \cdot c \cdot X \qquad (4)$$

where $\frac{do}{dt}$ = the rate of oxygen utilization,

$\frac{dF}{dt}$ = the rate of substrate utilization

a = the coefficient used to convert substrate units to oxygen units

b = microbial decay coefficient

c = coefficient used to convert cell mass units to oxygen units

x = the microbial cell concentration

If nitrification is the objective of the stabilization, oxygen requirements are increased

$$\frac{do}{dt} = a \cdot \left(\frac{dF}{dt} \right) + b \cdot c \cdot X + 3.43 \frac{d[NH_4^+]}{dt} + 1.14 \left(\frac{d[NO_2]}{dt} \right) \qquad (5)$$

where $\frac{d[NH_4^+]}{dt}$ and $\frac{dNO_2^-}{dt}$ are respectively, the rates of oxidation of ammonia to nitrite and nitrite to nitrate.

Earlier studies (4,5) conducted by the investigators of this project have indicated (i) that significant removals of nitrogen could be achieved by nitrification followed by denitrification; (ii) that nitrogen losses due to denitrification could occur under seemingly aerobic conditions;

(iii) that effective odor control could be achieved by stabilization of wastes in an oxidation ditch; (iv) that oxygen requirements for treatment with control and partial stabilization will be lower than for a system designed to achieve nitrification; and (v) that large concentrations of dissolved and suspended solids may hamper rates of oxygen transfer to the microorganisms during aerobic stabilization.

Studies (5) on land application and crop response to treated poultry manure indicated that (a) residual benefits from poultry manure to corn grain yields were evident the year following application; (b) the mineralization rate of nitrogen in poultry manure is about 50% as measured by crop response; (c) a comparison of the mixed liquor from an oxidation ditch treating poultry manure with raw poultry manure applied to prepared corn land in the spring resulted in no significant runoff losses of soluble phosphorus, nitrate, ammonium, soil losses or water runoff; and (d) oxidation ditch stabilized manure applied in the spring was a superior nitrogen source on orchard grass when compared with fresh poultry manure.

To develop design criteria for waste stabilization systems that integrate nitrogen control, additional experimental evidence has been collected on (i) the factors influencing nitrogen losses during aerobic biological stabilization of animal wastes; (ii) the effect of different modes of operation of a pilot plant scale oxidation ditch on nitrogen removal from the wastes; (iii) the performance of full scale waste stabilization systems at two poultry production operations; and (iv) the performance of an oxidation ditch system installed to control odors in an experimental mink farm.

Additional experimental evidence was collected on the evaluation of field application of stabilized poultry wastes from an oxidation ditch and raw or untreated sources by (a) measuring corn, bromegrass and orchard grass response to several manure sources, (b) measuring runoff losses of nitrate, ammonium, soluble phosphorus and soil from treated plots; and (c) measurement of residual effects of applied manure.

MATERIALS AND METHODS

Laboratory Studies

A series of studies were conducted to obtain detailed information on the factors affecting nitrogen control in aerobic systems. Details of the equipment, approaches, and methods used in these studies are outlined in this section. All the laboratory studies were conducted at room temperature (20°C - 23°C).

The required concentrations of the wastes were made by suspending the requisite amount of poultry manure in distilled water. The mixture was blended in a Waring blender and filtered through a single layer of cheesecloth to remove large particulate matter. The material retained on the cheesecloth was washed with distilled water to recover most of the soluble matter. The filtered suspensions were diluted to the required volume with distilled water.

Different quantities of ODML and poultry manure suspensions in tap water were aerated by placing Erlenmeyer flasks, containing the suspensions, on a variable speed rotary shaker. Rotary shaking not only aerated the samples but also provided adequate mixing of suspensions.

Analytical Methods

A mineral salts solution was used in certain experiments to resuspend centrifuged mixed liquor solids. The salt solution contained the following: $MgSO_4 \cdot 7H_2O$, 250 mg/l; $FeSO_4 \cdot 7H_2O$, 10 mg/l; $CaCl_2 \cdot 2H_2O$, 10 mg/l.

Mixed liquor from the pilot plant oxidation ditch was used in some laboratory experiments and is referred to in this report as ODML.

Total solids, volatile solids, and BOD were determined as described in *Standard Methods* (6). COD was determined by a rapid method (7).

Suspended solids were determined by filtering a known volume of the sample through glass filter paper. The weight of the dry solids retained on the filter paper was used as an estimate of the suspended solids. A considerable length of time was generally taken for the filtration of the relatively concentrated samples. In such situations, a part of the weight of the suspended solids may have included some dissolved solids.

The pH of the sample was measured with a Corning pH meter.

Ammonium nitrogen, nitrite and nitrate nitrogen were determined by a steam distillation procedure (8). NO_2-N was separately determined by a diazotization method (9), and its value was subtracted from the (NO_2+NO_3)-N value obtained by the steam distillation method to obtain the value of NO_3-N. Total Kjeldahl nitrogen (TKN) was determined by a micro-Kjeldahl method (10).

The concentration of dissolved oxygen in the samples was determined by using a YSI model 54 oxygen meter. The sensing element was a membrane covered polarographic probe which was compensated for temperature effects of both the probe membrane permeability and solubility of oxygen in water.

Routine methods of analysis (11, 12) were employed to examine plant tissues, manured and non-manured soils, soil leachate and runoff for the different forms of nitrogen. Soil leachates and runoff were also examined for orthophosphates and total soluble phosphates (12, 13, 14).

Storage of Samples

All the nitrogen analyses, COD, and BOD were performed on the samples rapidly and without storage. NO_2-N and NO_3-N analyses of samples stored with H_2SO_4 were found to be unsatisfactory. In the determination of solids, it sometimes was inconvenient to process all the samples in one day. On such occasions the samples were refrigerated and determinations were made as soon as possible.

Rate of Oxygen Transfer

Oxygen transfer rates of the aeration systems were determined in tap water for the different operating conditions of this study. Dissolved oxygen in the water was removed by adding 8 mg of sodium sulfite per mg of dissolved oxygen to deplete the dissolved oxygen adding cobalt chloride (0.1 mg per liter) as a catalyst. When the dissolved oxygen concentration reached zero, aeration was started and the changes in the concentration of dissolved oxygen was recorded by using a Honeywell Electronic recorder in conjunction with the oxygen meter. The oxygen transfer rate was computed using the following equation:

$$\frac{dc}{dt} = K_L a \, (C_s - C_t) \qquad (6)$$

where

$K_L a$ = oxygen transfer rate

$\frac{dc}{dt}$ = change in dissolved oxygen with time

C_s = saturation concentration of dissolved oxygen

C_t = concentration of dissolved oxygen at time t.

The rate of oxygen transfer into a microbiologically active mixed liquor can be represented by the following modification of equation (6):

$$\frac{dc}{dt} = K'_L a \, (C'_s - C_t) - R_r \qquad (7)$$

where

$K'_L a$ = oxygen transfer rate into the mixed liquor

C'_s = saturation concentration of dissolved oxygen in the mixed liquor

C_t = concentration of dissolved oxygen at time t

and R_r = oxygen uptake rate of the mixed liquor

When the microbiologically active mixed liquor exerting an oxygen demand is being aerated and the system has reached a steady state with respect to the concentration of dissolved oxygen, then dc/dt = 0, and

$$K_La = \frac{R_r}{C_s - C_{eq}} \qquad (8)$$

where

C_{eq} = the concentration of dissolved oxygen at the steady state condition

To determine the concentration of dissolved oxygen at steady state conditions, the probe was placed in the liquid that was being aerated. The changes in the concentration of dissolved oxygen were followed.

After the system had reached a steady state with respect to dissolved oxygen, the aeration was stopped and the profile of the changes in the concentration of dissolved oxygen with time was recorded. The oxygen uptake rate was calculated using the recorded data.

The value of the saturation concentration of dissolved oxygen in water at different temperatures was obtained from the tables (6). The value of C_s was corrected to actual atmospheric pressure by the following equation:

$$C_s \text{ (actual)} = C_s \text{ (tabulation value)} \frac{\text{Atmospheric pressure (inches Hg)}}{29.92} \qquad (9)$$

The saturation concentration of dissolved oxygen in a mixed liquor (C'_s) can be calculated by using the following equation:

$$C_s \text{ (actual)} = \beta \cdot C_s \text{ (actual)}$$

The value of β for poultry wastes was assumed to equal one.

The experimental evidence collected at the AWML (Agricultural Waste Management Laboratory, College of Agriculture and Life Sciences, Cornell University) have indicated that the concentration of total solids in the ODML significantly affect the oxygen transfer relationships (Fig. 1). In this study, the relationship between α and total solids content of the mixed liquor shown in Fig. 1 was utilized to calculate the oxygen transfer rates in suspensions of varying solids concentration.

Pilot Plant Oxidation Ditch Studies

The oxidation ditch at the Agricultural Waste Management Laboratory has been operating and evaluted continuously since 1970. During the period of this project it was operated at various solids concentrations. Nitrogen mass balances were made and the nitrogen losses in the ditch were related to the varying operating conditions.

The concentration of total solids in the oxidation ditch was varied by altering the water input to the ditch. The operational control of the total solids content necessitated the installation of an automatic overflow in addition to control of water input to the ditch. The data collected in this study included: rotor immersion depth, waste output, water input, rates of oxygen uptake, temperature, COD, total and volatile solids, and organic, ammonia, nitrite and nitrate nitrogen.

Solids concentrations were changed only after a suitable equilibrium period was established. During the study, the immersion depth of the rotor was increased whenever the concentration of dissolved oxygen in the mixed liquor was close to zero. The reduction in dissolved oxygen concentration

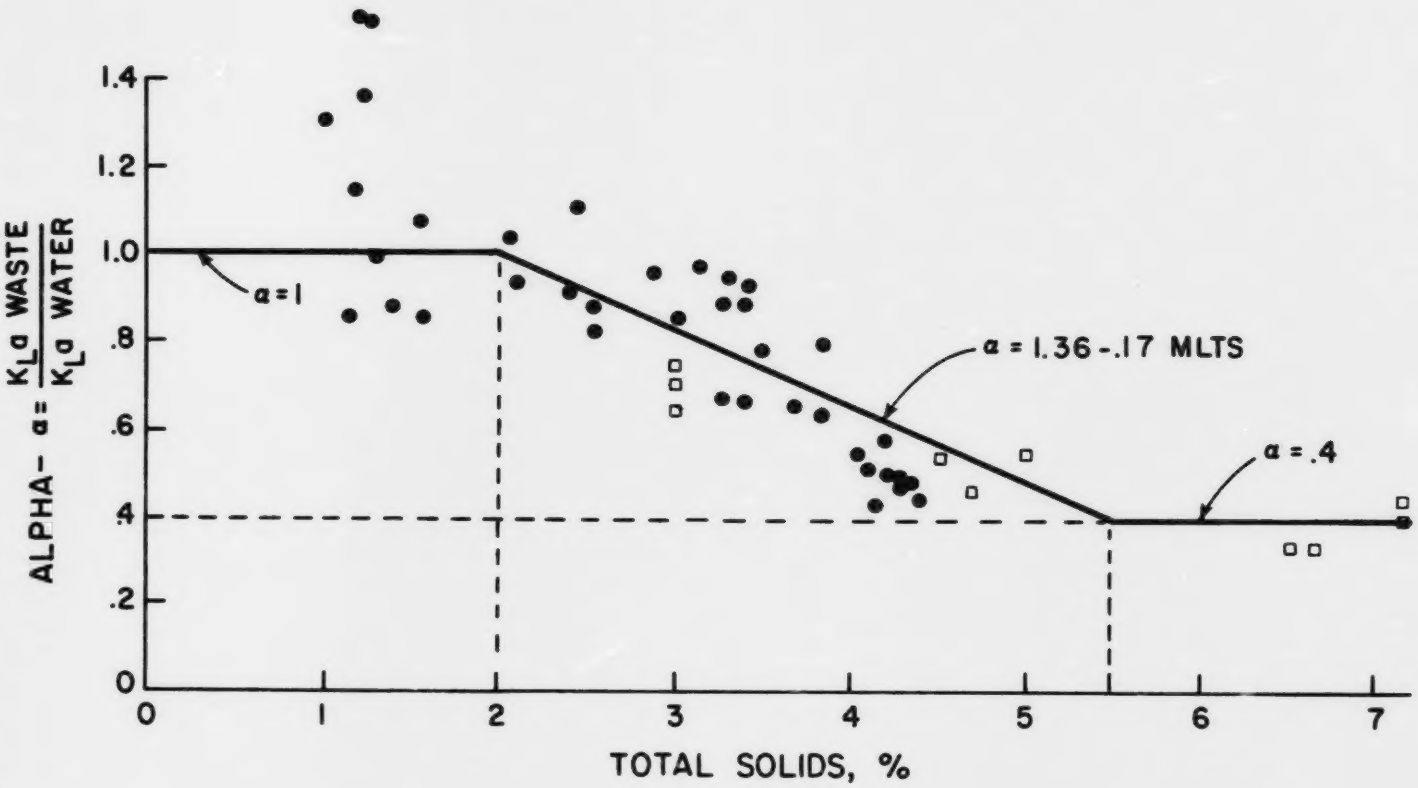


Figure 1. Effect of total solids concentrations on α in a poultry waste mixed liquor (Calhoun, 1974)

occurred as a result of the decreased oxygen transfer capabilities of the rotor as the solids concentration increased. Thus an equilibrium period consisted of more than one sub-phase if the rotor immersion depth was changed.

Modes of operation - To evaluate nitrogen losses in the oxidation ditch, the following modes of operation were studied: a) continuous rotor operation and without intentional wasting of the mixed liquor; i.e., as an aerated holding tank with continuous addition of wastes (Fig. 2a), b) maintenance of a solids equilibrium condition by intentionally wasting some mixed liquor and subjecting the remaining mixed liquor to intermittent denitrification (Fig. 2b), c) maintenance of solids equilibrium and using a solids separation tank to settle the mixed liquor suspended solids and to denitrify the recycled effluent (Fig. 2c), d) intermittent periods of rotor aeration which permitted nitrification and denitrification. In this mode, the rotor was connected via a time switch which controlled the time of operation of the rotor (Fig. 2d). When the rotor was operating, aerobic conditions prevailed in the mixed liquor and nitrification was sustained. When the rotor was off, anoxic conditions resulted in the mixed liquor and denitrification occurred.

Studies With Other Oxidation Ditches

The technical feasibilities of the waste management principles were evaluated and the managerial problems associated with the process were identified by monitoring the waste stabilization facilities at (a) two commercial poultry farms, and b) an experimental mink farm. The studies on the operation of the oxidation ditch at the mink farm were mainly to verify the applicability of pilot plant design and operation principles for poultry wastes to treatment systems for other animal wastes. The following is a brief description of these three facilities:

(a) A commercial 15,000 bird poultry operation owned by Mr. Charles Houghton, a farmer. An oxidation ditch system had been installed to control odors.

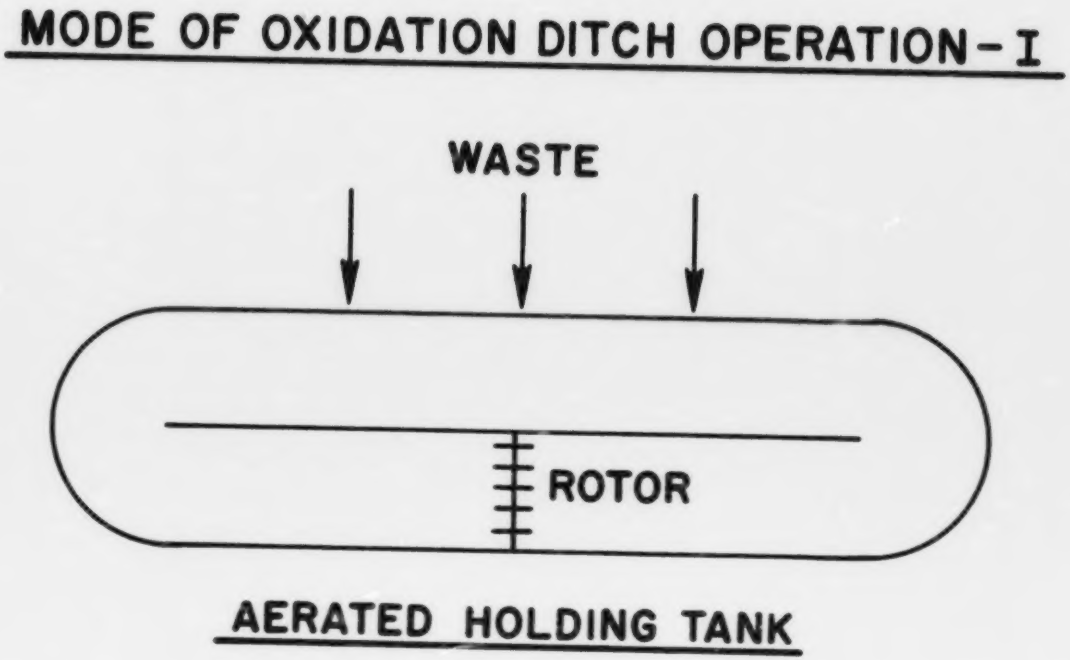

MODE OF OXIDATION DITCH OPERATION-I
WASTE
ROTOR
AERATED HOLDING TANK

Figure 2a. Mode of oxidation ditch operation I.

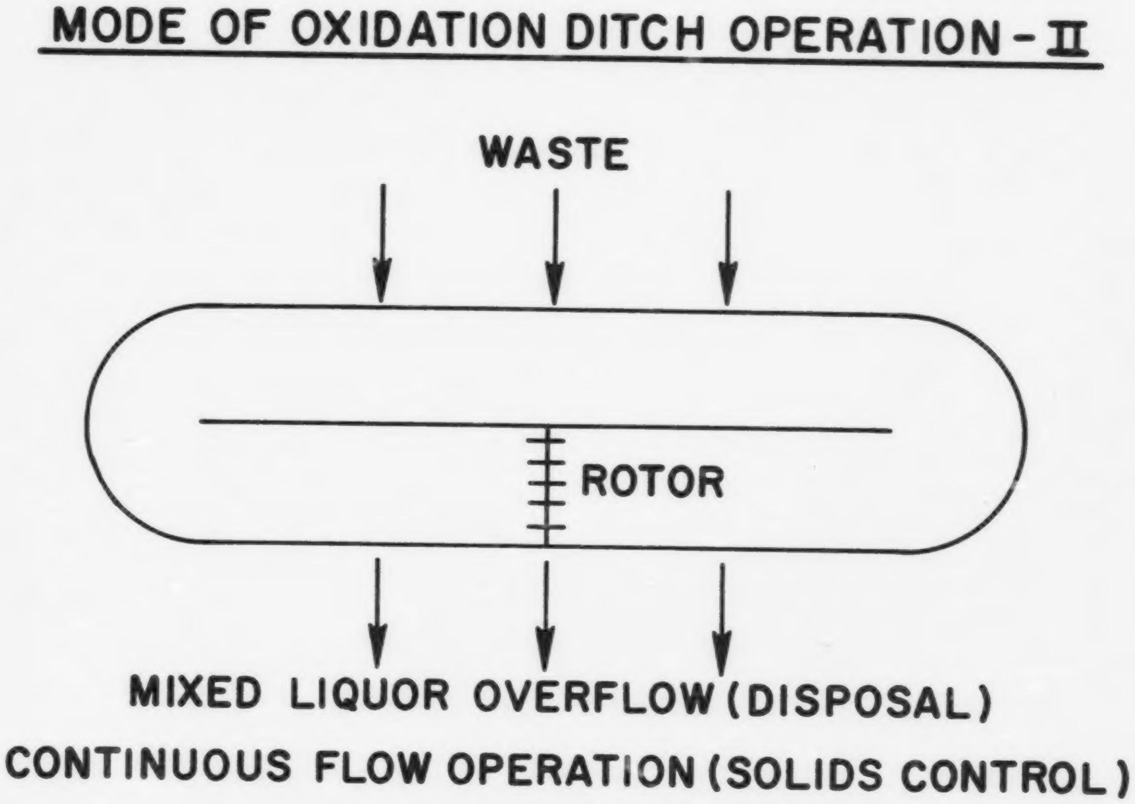
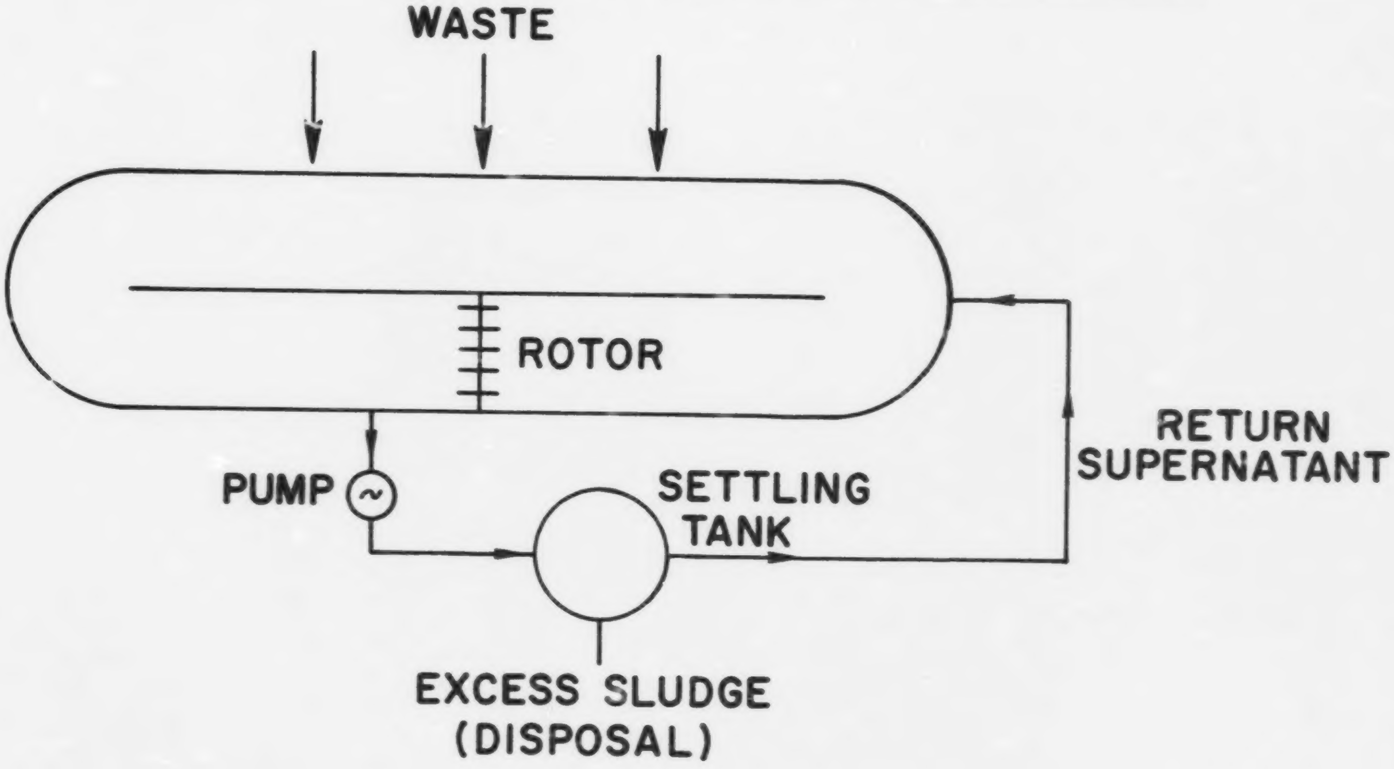

MODE OF OXIDATION DITCH OPERATION - II
WASTE
ROTOR
MIXED LIQUOR OVERFLOW (DISPOSAL)
CONTINUOUS FLOW OPERATION (SOLIDS CONTROL)

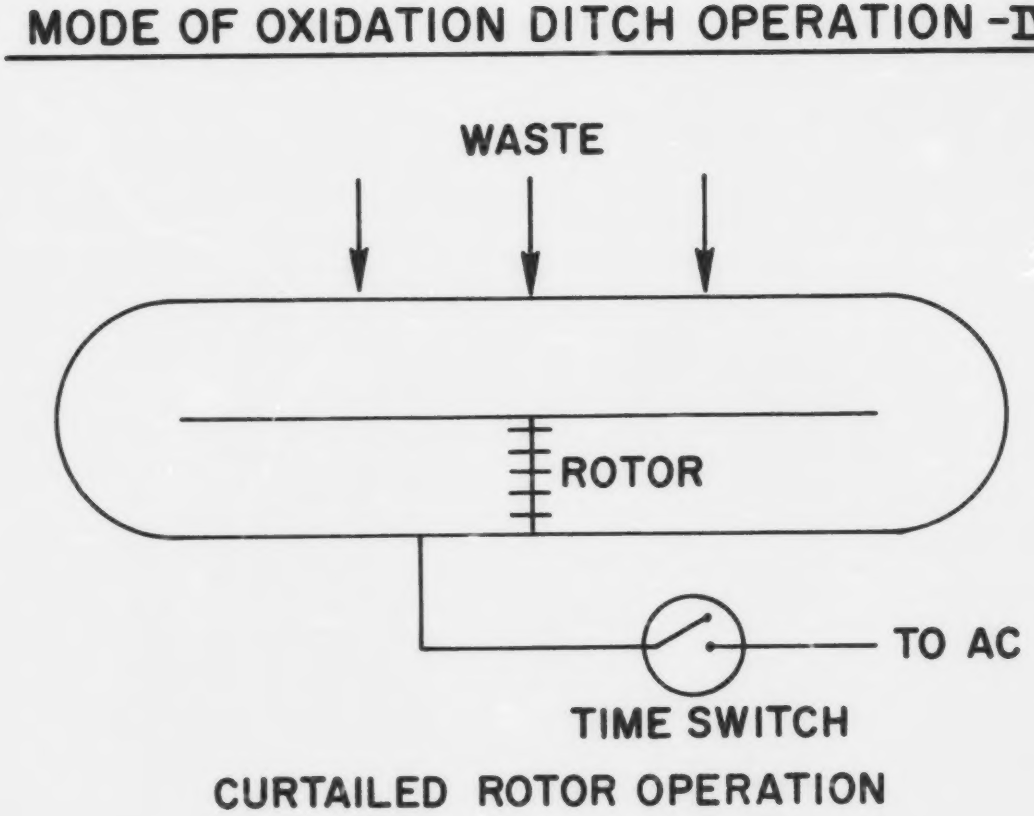
Figure 2b. Mode of oxidation ditch operation II.

MODE OF OXIDATION DITCH OPERATION - III


WASTE
ROTOR
PUMP
SETTLING TANK
RETURN SUPERNATANT
EXCESS SLUDGE (DISPOSAL)

SOLIDS EQUILIBRIUM WITH A SETTLING TANK AND RECYCLING OF SUPERNATANT

Figure 2c. Mode of oxidation ditch operation III.



MODE OF OXIDATION DITCH OPERATION -IV

WASTE
ROTOR
TO AC
TIME SWITCH

CURTAILED ROTOR OPERATION

Figure 2d. Mode of oxidation ditch operation IV.

Personnel of Cornell provide technical assistance and monitoring of the waste treatment system.

(b) A commercial 30,000 bird poultry operation at Camillus, New York, owned by Manorcrest Farms. Two of the three poultry houses in this farm are being utilized to demonstrate the performance of aeration systems to stabilize poultry wastes. This demonstration is supported by an EPA grant-EPA project number S800863. Cornell University personnel are in charge of the engineering and analytical aspects of this project.

(c) A mink farm sponsored by the USDA in a cooperative program with Cornell University. Advances made in fur animal husbandry have shown the economic advantages resulting from raising mink in closed sheds with light and temperature control. An oxidation ditch system was installed to control odors. Cornell University personnel designed the system and provided technical assistance and monitoring of the waste treatment system.

Calculation of Nitrogen Losses

A loss of nitrogen has been consistently observed in the aerobic laboratory units containing nitrified poultry wastewater and in the aerobic nitrifying oxidation ditches. This loss was computed as the difference between the amount of nitrogen that was fed to the system and the nitrogen that was actually present in the mixed liquors plus any nitrogen that was removed deliberately from the system such as for disposal or analysis. These losses were attributed to denitrification and ammonia volatilization. The gas traps in the laboratory systems permitted an estimate of the ammonia volatilization losses. No effort was made to measure ammonia losses in the oxidation ditch studies because of the inherent difficulties in such measurements.

If the possibility of nitrogen loss due to ammonia volatilization is excluded or known, the observed nitrogen losses can be attributed to denitrification. Nitrogen mass balances in the aerobic systems should therefore take into consideration the two sources of nitrogen losses. The relationship between the nitrogen added, nitrogen content of the system and the losses can be expressed by the following:

Total Nitrogen Added = Total Nitrogen in the system
+ nitrogen lost due to ammonia volatilization
+ nitrogen lost due to denitrification
+ nitrogen removed from the system for disposal or analysis

Nitrogen losses due to ammonia desorption from the flasks kept on the rotary shaker were estimated by using the following relationship:

$$\text{Quantity of nitrogen lost from the system} = K_D \cdot F \cdot t \cdot [(\text{volume of liquid})(\text{concentration of } NH_4\text{-N})]$$

where K_D is the coefficient of ammonia desorption

$$F = \frac{10^{pH}}{10^{pH} + K_{b/k_w}}$$, (K_b and k_w are the dissociation constants of ammonia and water)

t = duration of ammonia desorption.

K_D was experimentally determined by following the ammonia losses from solutions of ammonium sulfate in water, rendered alkaline by addition of sodium hydroxide.

Land Application of Wastes

A series of field studies were established to obtain information on the fate of nitrogen in manure applied to soils to promote crop growth. These studies included two sources of poultry manure, three rates of application and, in two of the three experiments, two different times of application.

An additional study was designed to study nitrogen balances in the soil and corn plant in order that fertilization and manuring practices could be regulated to result in minimum water pollution with economic corn production.

Surface Runoff Losses, Field Studies

Two field studies permitted the collection of surface water runoff from plots that had received application of poultry manure. The two manures used were poultry manure stabilized by an oxidation ditch and fresh poultry manure. Application rates of 0, 112, 224 kg N/ha were used. The first study was established in 1972 on a Collamer silt loam soil near the Ithaca Poultry Farm, Cornell University. The second study was established at the Agronomy Research Farm at Cornell University on a high lime Honeoye silt loam.

Weed control was accomplished through the application of chemical herbicides to the soil surface prior to plowing. Manure was applied as a surface application and plowed in within two days of application.

Individual plots measured 3.0 by 9.1 m and were surrounded by raised, corrugated aluminum lawn edging so that only runoff from the plots were collected. At the base of the plot slopes, collection troughs were installed and were connected to a flow divider to divert one-twentieth of the entire amount of flow into a storage tank. Runoff water was then measured and analyzed for soluble orthophosphate (13), ammonium (15), nitrite nitrate (16), and total soluble phosphorus (14). Sediment samples were collected and analyzed for total phosphorus (17), total Kjeldahl nitrogen (11), and organic matter (12). Soil samples were taken at regular intervals and at two depths, 0-20 cm and 30-60 cm. Soil samples were analyzed for ammonium, nitrate nitrogen, and total Kjeldahl nitrogen.

Analysis of the stabilized oxidation ditch mixed liquor that was applied is presented in Table 2.

Table 2. COMPONENTS OF OXIDATION DITCH MANURE USED AS A SOURCE OF N FOR FIELD STUDIES, 1973

Parameter	Concentration (mg/ℓ)
TKN	3,360
NH_4N	1,274
NO_3N	0
NO_2N	0
COD	28,806
Solids	28,485

Poultry Waste Residue Field Study

A field study was initiated in 1971 at the Aurora Research Farm on a Honeoye silt loam soil. Plots measuring 3.0 by 18.2 m were established using untreated poultry manure at the rates of 0, 56, 112, 224, 448, and 896 kg N/ha. A seventh treatment consisted of commercial fertilizer at the rate of 22.4 kg N/ha. Corn was grown on all plots.

In 1972, the original plots of this study were split and the same treatments repeated on one-half the original plots (Fig. 3). Corn was grown again on these plots. In 1973, manure was applied only to the treatments that had received 112 and 448 kg N/ha in 1972. Forty-five kg N/ha were applied to the commercial fertilizer treatment (Fig. 3). In 1974, none of the treatments received manure but 90 kg N/ha was applied to the treatment receiving a commercial source of N. Corn was the crop grown each year. Corn grain and stover yields were determined on each plot each year. Corn grain and stover were analyzed for total N. Soil samples were collected at regular intervals and analyzed for nitrate and ammonium.

	POULTRY MANURE						CHEM. FERT.
1971	0	56	112	224	448	896	22
	0	56	112	224	448	896	22
1972	0	0	0	0	0	0	0
	0	56	112	224	448	896	22
1973	0	0	0	0	0	0	0
	0	0	112	0	448	0	45
1974	0	0	0	0	0	0	0
	0	0	0	0	0	0	90

NITROGEN, kg/ha

Figure 3. Nitrogen applied over a 4-year period as poultry manure or chemical fertilizer. Poultry waste residue study, 1971-1974.

Forage Grass Response

A study to determine orchard grass and bromegrass response to applications of poultry manure was conducted. Application rates of 0, 56, 112, and 224 kg N/ha were made using stabilized oxidation ditch mixed liquor and fresh poultry manure as N sources. These rates were applied to established grass stands in both fall and spring. Two cuttings of grass were harvested from each plot.

GENERAL OBSERVATIONS ON THE RESULTS OBTAINED

Experiments were conducted in the laboratory to examine the effect of different factors influencing stabilization of wastes, nitrification and losses of nitrogen. The following factors were examined: (a) rate of loading; (b) pH value; (c) total solids; (d) total Kjeldahl nitrogen (TKN); and (e) COD. The effect of several different loadings were examined by following the changes occurring in mixtures containing varying amounts of poultry waste suspensions and nitrifying ODML. The samples of ODML used in this study were from the oxidation ditches at (a) pilot plant, and (b) Manorcrest Farm. The effect of the other factors were studied by altering the pH value, COD, total solids, and TKN contents in the systems. The ranges of these variables examined are indicated in Table 3. At the same time, some large scale studies were conducted at the pilot plant on the effect of different modes of operation of oxidation ditches on nitrogen contents of stabilized wastes.

The laboratory and pilot plant studies, and the observations on the performance of the oxidation ditches at (a) the fur animal experiment station; and (b) the two commercial poultry operations, indicated that significant reductions in COD, total solids, and nitrogen contents occur during aerobic stabilization. No objectionable odors were produced during the aerobic stabilization of the manures.

Table 3. COMPONENTS OF NITRIFYING WASTE SUSPENSIONS AND THE INITIAL CONDITIONS IN THE LABORATORY-SCALE NITRIFICATION SYSTEMS

(a) Components of the mixtures used:

	Water (ml)	ODML (ml)	Poultry waste suspension (ml)
Control	500	1500	0
System I	100	1500	400
System II	200	1500	300
System III	300	1500	200
System IV	400	1500	100

(b) Ranges of pH, NH_4^+-N, $(NO_2 + NO_3^-)$ N, and TKN:

	pH	NH_4^+-N (mg/l)	NO_2+NO_3-N (mg/l)	TKN (mg/l)
Trial 1	6.8 - 6.9	0 - 10	830	440 - 1470
Trial 2	7.0 - 8.1	0 -120	800	370 - 1150
Trial 3	7.0 - 7.7	6 -200	430	1200 - 2300
Trial 4	6.9 - 7.8	0 -120	10 - 70	900 - 2700
Trial 5	8.0 - 8.6	60 -450	170 - 260	875 - 3500
Trial 6	7.0 - 8.4	10 -350	110 - 150	650 - 3500
Trial 7	5.6 - 7.0	120 -320	550 - 820	530 - 2800

Nitrification occurred in all the stabilization systems examined. Nitrogen balances on the systems indicated that nitrogen losses occurred during stabilization. These losses could be attributed to either desorption of ammonia or dissimilatory denitrification of the oxidized nitrogen. Desorption of ammonia occurs at high pH values. Denitrification takes place when the concentration of dissolved oxygen inthe system reaches zero, and when nitrites and nitrates function as electron acceptors during the oxidation of carbonaceous substrate.

Corn, orchard grass and bromegrass responded to the application of raw poultry wastes as well as the oxidation ditch mixed liquor. These responses were directly proportional to the amount of nitrogen applied to the land up to 224 kg per ha for corn and 170 kg per ha for the grasses. The responses did not appear to be significant beyond these levels of nitrogen application. There were some seasonal differences in the responses of corn and grasses. Some nitrogen from the manures applied to the bare ground in the fall was leached from the soil or denitrified as shown by soil analysis and crop response. Grasses on the same soil retained the nutrients so that yields from the fall application were equal to those from spring application. Application of manures increased the nitrate content of the soils, but did not cause any runoff problems during the growing season at the levels of application examined.

The details of the results of these experiments are described in sections IV and V, and the significance of these results are discussed in section VI.

SECTION IV

RESULTS OF THE ENGINEERING STUDIES ON NITROGEN CONTROL

LABORATORY STUDIES

In all the stabilization systems examined in the laboratory, the concentrations of dissolved oxygen were less than 1 mg per liter on the first day of stabilization. Later, the dissolved oxygen concentrations increased to more than 7 mg per liter. The oxygen uptake rates increased during the first 24 hours and later decreased as the process of stabilization proceeded (Fig. 4). TKN and COD concentrations decreased as stabilization proceeded.

In the systems which had an initial pH value of 7.0 and a high organic load, the pH values increased as the organic nitrogen compounds were hydrolyzed, and subsequently decreased later as nitrification occurred (Fig. 5). The nitrogen balances showed that some losses of nitrogen could neither be ascribed to ammonia desorption nor to decreases in the nitrate contents. These unaccountable losses are presumably due to the denitrification of NO_3 occurring in the sludge flocs in the system under seemingly aerobic conditions.

Some of the salient observations on the changes that occurred in the different laboratory trials are described under separate subheadings.

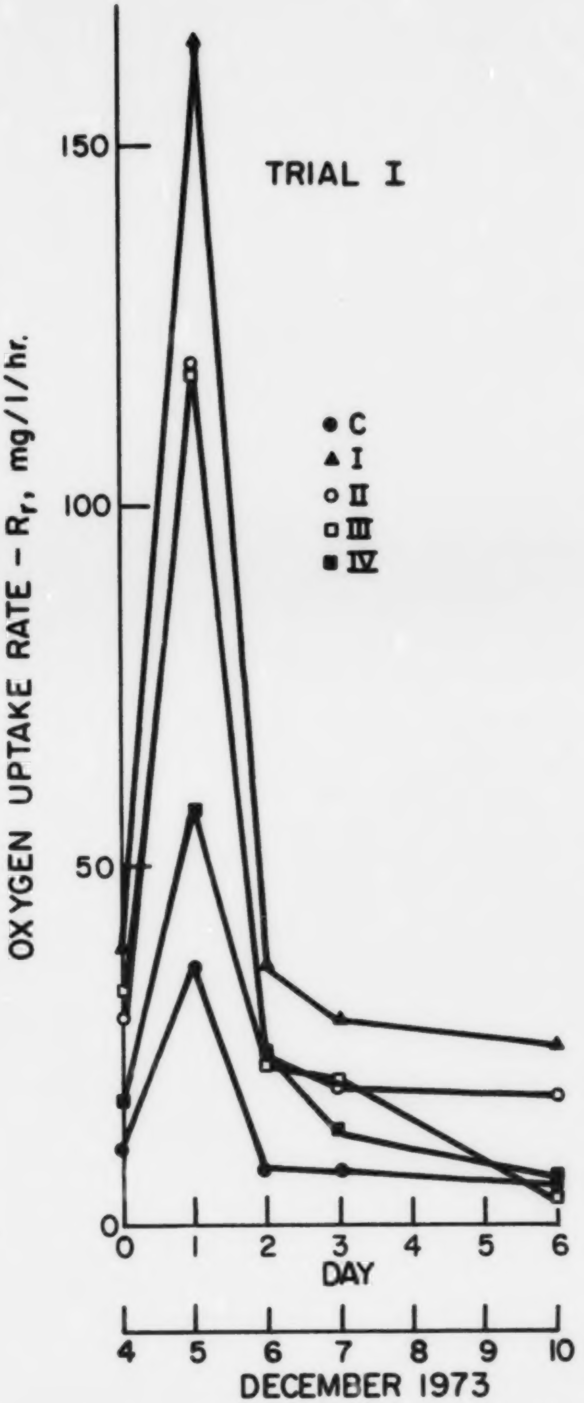


Figure 4. Changes in the oxygen uptake rate during waste stabilization.

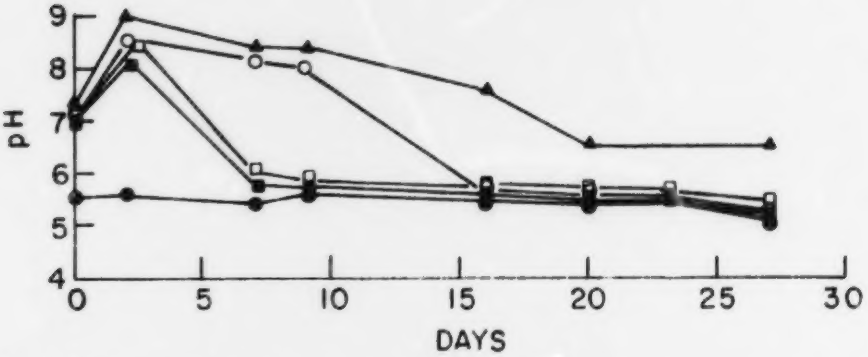


Figure 5a. Changes in pH during stabilization and nitrification.

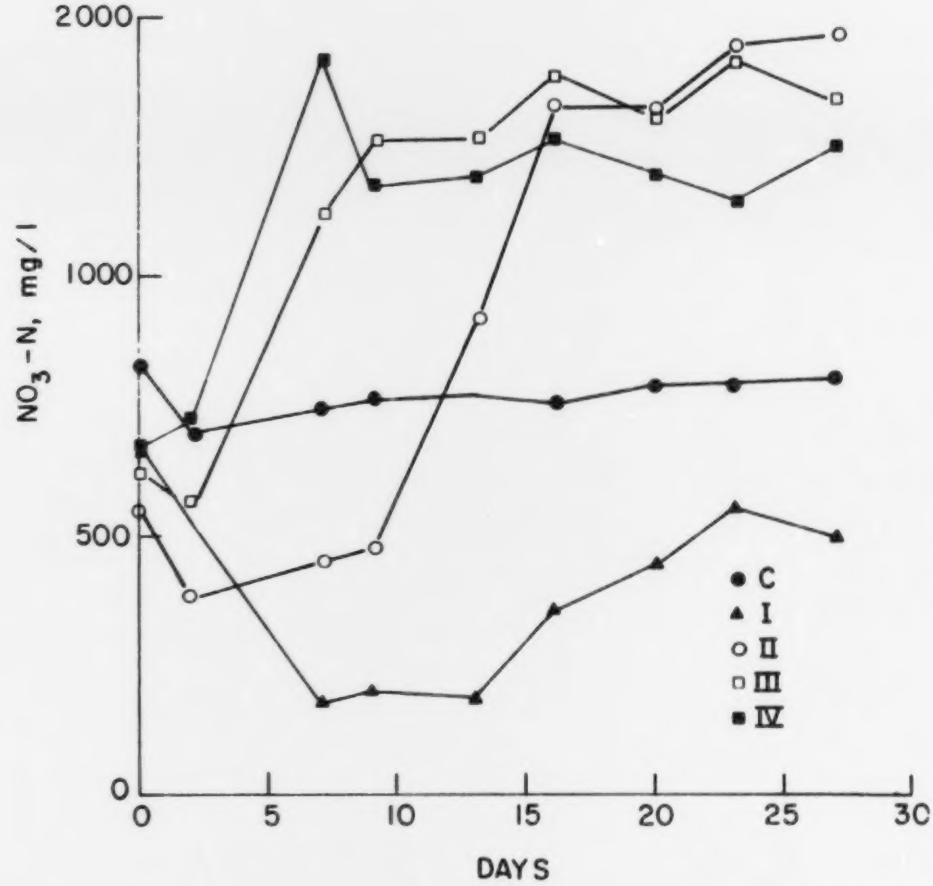


Figure 5b. Changes in concentration of nitrates during stabilization and nitrification.

Trial #1

In this trial, the systems were started at a low pH value. As the stabilization proceeded, the pH values of systems 1, 2, and 3 increased to 8.5 before they decreased to 5.3. The concentration of oxidized nitrogen steadily increased as the stabilization proceeded.

In the control system and in system 4, the changes in pH were not significant so as to cause losses of nitrogen due to desorption of ammonia. In systems 1, 2, 3, and 4, decreases in nitrate contents were noted. The nitrogen losses from the systems and the estimates of losses due to (a) ammonia desorption; (b) denitrification; are shown in Table 4. The unaccountable losses shown in Table 4 are presumably due to denitrification.

Trial #2

The changes in the total nitrogen content of the different systems are shown in Figure 6. The nitrogen losses and the estimates of losses due to ammonia desorption and denitrification are summarized in Table 5. The losses of nitrogen due to denitrification occurring in the sludge flocs have been shown in the table as unaccountable nitrogen losses. The cumulative oxygen uptake data presented in Figure 7 indicate that higher oxygen demand is exerted by units having higher nitrogen concentrations.

Trial #3

In the control system of this trial, the mixed liquor did not contain any significant amount of NH_4^+- N. The content of oxidized nitrogen steadily increased. In system 1, there was no apparent decrease in the nitrate content. In systems 2, 3, and 4, decreases in nitrate contents were noted

Table 4. NITROGEN LOSSES DUE TO AMMONIA DESORPTION AND DENITRIFICATION IN THE STABILIZATION SYSTEMS OF TRIAL #1

System	pH Range	TKN (mg/l)		(NO_2+NO_3)-N (mg/l)		Nitrogen Loss (mg/l)			
		Initial	Final	Initial	Final	Ammonia Desorption(est.)	Observed Denitrification	U.A.*	Total
Control	5.9-6.8	438	343	829	874	0	0	50	50
1	5.2-8.5	1470	798	829	776	318	67	340	725
2	5.3-8.3	1176	711	792	454	233	682	-	915
3	5.3-8.1	928	396	650	1184	114	262	-	333
4	5.4-7.6	770	410	759	1280	0	458	-	385

*U.A.-unaccountable

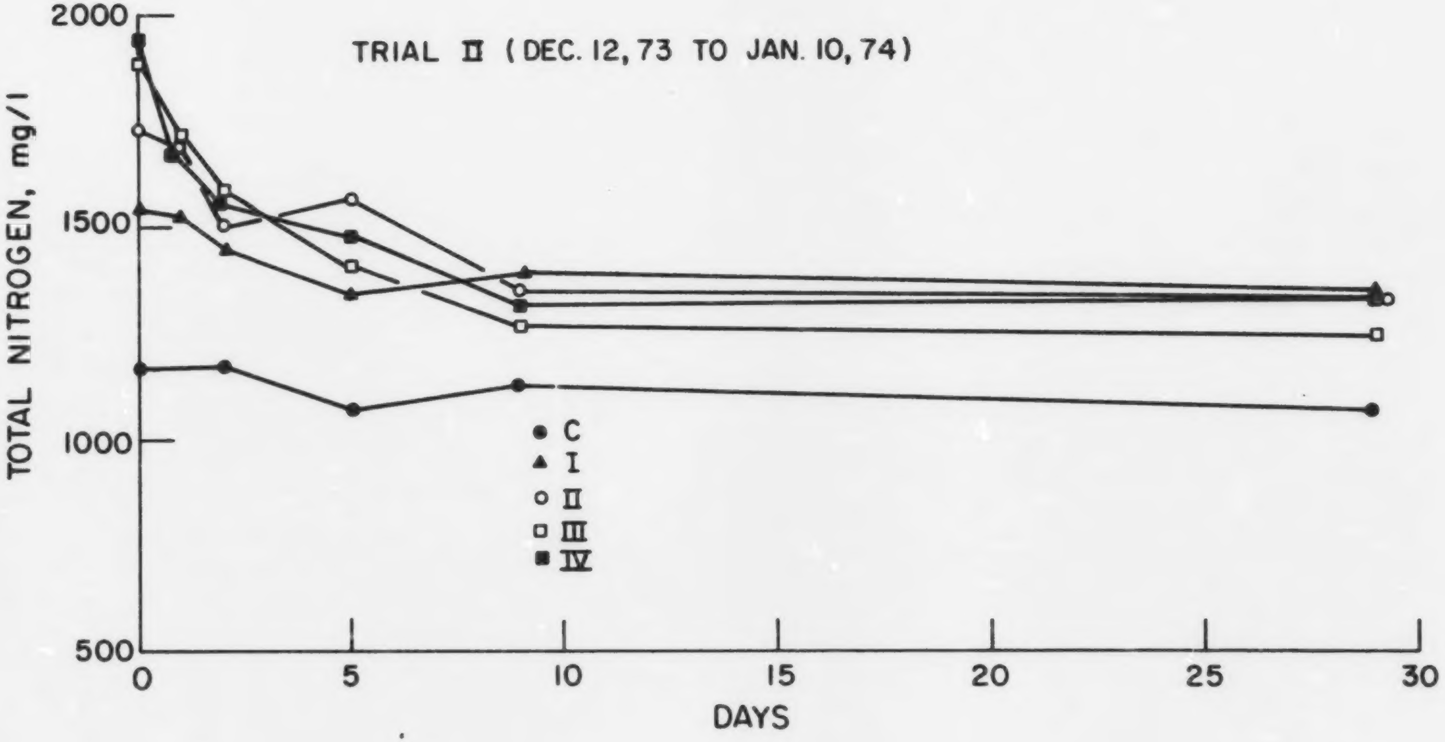


Figure 6. Total nitrogen contents of the wastes in the different systems during stabilization.

Table 5. NITROGEN LOSSES DUE TO AMMONIA DESORPTION AND DENITRIFICATION IN THE STABILIZATION SYSTEMS OF TRIAL #2

System	pH Range	TKN (mg/1)		(NO_2+NO_3)-N (mg/1)		Nitrogen Loss (mg/1)			
		Initial	Final	Initial	Final	Ammonia Desorption (est.)	Observed Denitrification	U.A.*	Total
Control	6.7-7.0	371	322	804	756	0	48	49	97
1	6.4-8.0	742	322	804	1027	170	0	27	197
2	6.2-8.2	917	357	804	980	117	158	109	384
3	6.3-8.2	1085	361	804	890	114	336	188	638
4	6.5-8.0	1144	462	804	874	130	482	-	612

*U.A.-unaccountable

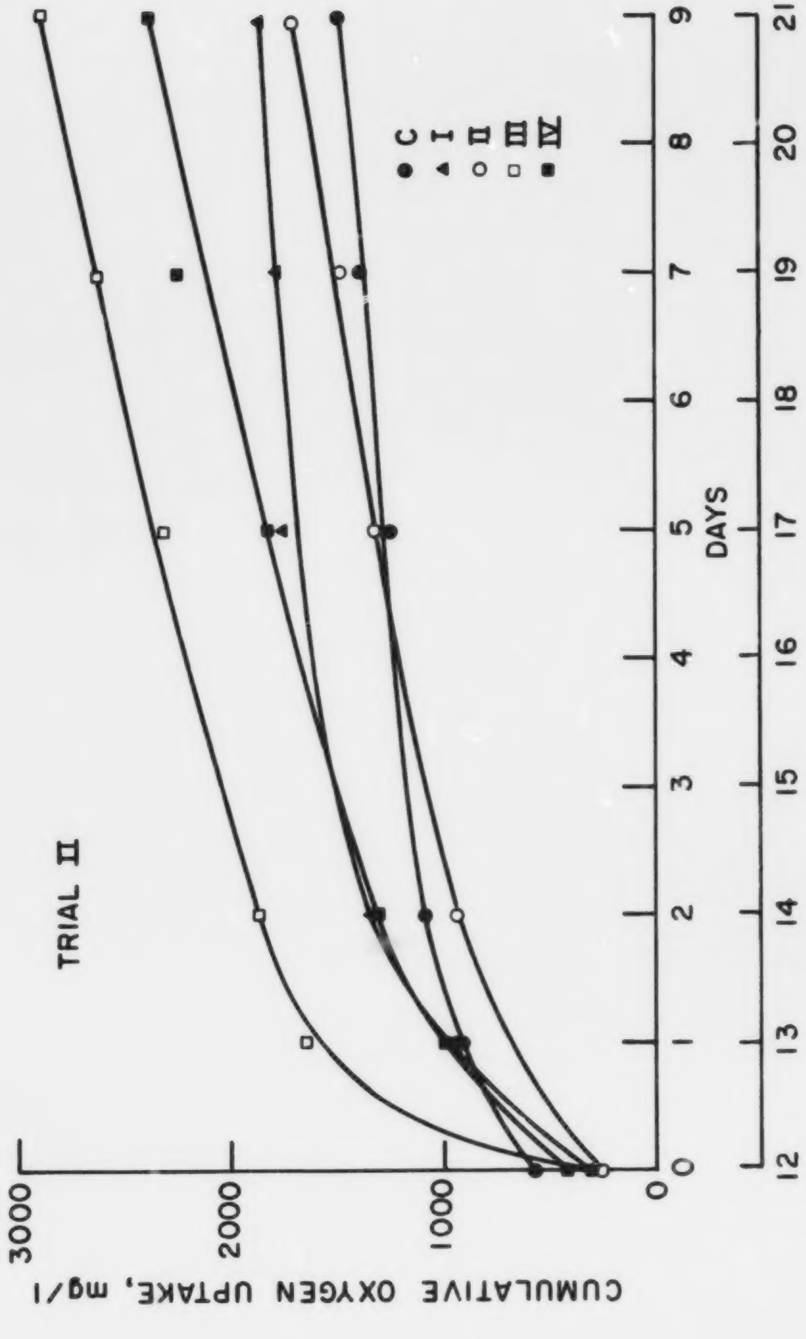


Figure 7. Cumulative oxygen uptake over time.

during the course of stabilization. The initial and final concentrations of nitrogen, and the losses of nitrogen due to the three different mechanisms given in Table 6.

Trial #4

The control system and system 4 contained only traces of NH_4-N. Decreases in nitrate contents were noted in all the systems. The initial and final concentrations of nitrogen in the systems, and the losses of nitrogen due to the three different mechanisms are given in Table 7. Nearly half the amount of the total nitrogen of system 4 was lost during stabilization due to denitrification under seemingly aerobic conditions.

Trial #5

Losses of nitrogen due to ammonia desorption occurred in systems 1, 2, 3, and 4. The pH values of the liquor in the control system during the period of this study were in the range of 5.9 to 6.1. Thus, there were no losses due to ammonia desorption. During the course of stabilization, decreases in nitrate contents in systems 1, 2, 3, and 4 were noted. The results of this study are summarized in Table 8.

Trial #6

The changes in nitrogen contents of the systems, and the extent of nitrogen losses due to the different mechanisms are given in Table 9. NH_4-N was found only in trace amounts in the control system. Nitrogen losses due to ammonia desorption occurred in the systems 1, 2, 3, and 4. The amounts of nitrogen losses due to ammonia desorption were directly related to the initial TKN contents of the system (Table 9). Some decreases in the nitrate contents were noted during the course of stabilization in systems 1, 2, 3, and 4.

Table 6. NITROGEN LOSSES DUE TO AMMONIA DESORPTION AND DENITRIFICATION IN THE STABILIZATION SYSTEMS OF TRIAL #3

System	pH Range	TKN (mg/l)		(NO_2+NO_3)-N (mg/l)		Nitrogen Losses (mg/l)			
		Initial	Final	Initial	Final	Ammonia Desorption(est.)	Observed Denitrification	U.A.*	Total
Control	7.7-8.2	1215	707	431	596	0	0	343	343
1	7.5-8.3	1274	672	229	487	94	0	250	344
2	7.3-8.7	1701	774	210	442	150	210	335	695
3	7.2-8.8	1939	1092	160	431	287	224	65	576
4	7.1-8.9	2296	1256	123	342	525	143	153	821

*U.A.-unaccountable

Table 7. NITROGEN LOSSES DUE TO AMMONIA DESORPTION AND DENITRIFICATION IN THE STABILIZATION SYSTEMS OF TRIAL #4

System	pH Range	TKN (mg/l)		(NO_2+NO_3)-N (mg/l)		Nitrogen Loss (mg/l)			
		Initial	Final	Initial	Final	Ammonia Desorption(est.)	Observed Denitrification	U.A.*	Total
Control	7.0-7.8	903	455	73	294	0	56	171	227
1	7.8-8.0	1124	448	39	353	321	50	-	362
2	7.3	1593	644	22	487	378	17	89	484
3	7.2	2107	864	17	406	617	17	220	854
4	6.9	2720	889	14	378	0	53	1414	1467

*U.A.-unaccountable

Table 8. NITROGEN LOSSES DUE TO AMMONIA DESORPTION AND DENITRIFICATION IN THE STABILIZATION SYSTEMS OF TRIAL #5

System	pH Range	TKN (mg/l)		(NO_2+NO_3)-N(mg/l)		Nitrogen Loss (mg/l)			
		Initial	Final	Initial	Final	Ammonia Desorption (est.)	Observed Denitrification	U.A.*	Total
Control	5.9-6.1	875	525	260	465	0	0	-	-3
1	7.0-8.8	3465	2352	179	36	997	179	80	1256
2	8.4-8.6	3136	1971	224	42	840	507	-	1347
3	6.8-8.6	2699	1050	252	370	785	340	406	1531
4	6.2-8.6	1813	865	190	644	371	498	-	494

*U.A.-unaccountable

Table 9. NITROGEN LOSSES DUE TO AMMONIA DESORPTION AND DENITRIFICATION IN THE STABILIZATION SYSTEMS OF TRIAL #6

System	pH Range	TKN (mg/l)		(NO_2+NO_3)-N (mg/l)		Nitrogen Loss (mg/l)			
		Initial	Final	Initial	Final	Ammonia Desorption(est.)	Observed Denitrification	U.A.*	Total
Control	7.2	648	403	153	322	0	0	76	76
1	7.0-8.9	3535	1638	115	364	1554	126	-	1648
2	7.1-8.9	2695	1355	115	342	895	173	45	1113
3	7.3-8.8	2307	973	120	557	579	109	209	897
4	7.4-8.4	1820	770	112	742	238	96	86	420

*U.A.-unaccountable

Trial #7

Nitrogen losses due to ammonia desorption were neglible in all the systems examined in this trial. The cumulative oxygen uptake of the systems as a function of the period of stabilization is shown in Fig. 8. The TKN contents of the systems during the period of this study are shown in Fig. 9. The cumulative oxygen uptake and the removals of COD and nitrogen obtained in the systems are given in Table 10a. These results indicate that the removal of COD and nitrogen is directly related to oxygen uptake by the systems. Results given in Table 10b suggest that nitrogen losses due to denitrification appear to be: (a) directly proportional to oxygen uptake rates in the systems; and (b) inversely proportional to the equilibrium dissolved oxygen concentrations in the systems.

PILOT PLANT STUDIES

As the oxidation ditch began operation, losses of nitrogen due to ammonia volatilization were observed. These losses became minimal once nitrification was established and the pH dropped below 7.0. Except for some initial ammonia odor, the oxidation ditch had no odor during the various modes of operation, thus confirming that these systems can be used as effective devices for odor control. Some foaming occurred during transition from one mode of operation to another. This was not a severe problem since the foam subsided quickly as equilibrium occurred.

Material balances were computed for nitrogen and COD for each mode of operation to ascertain the performance of the ditch.

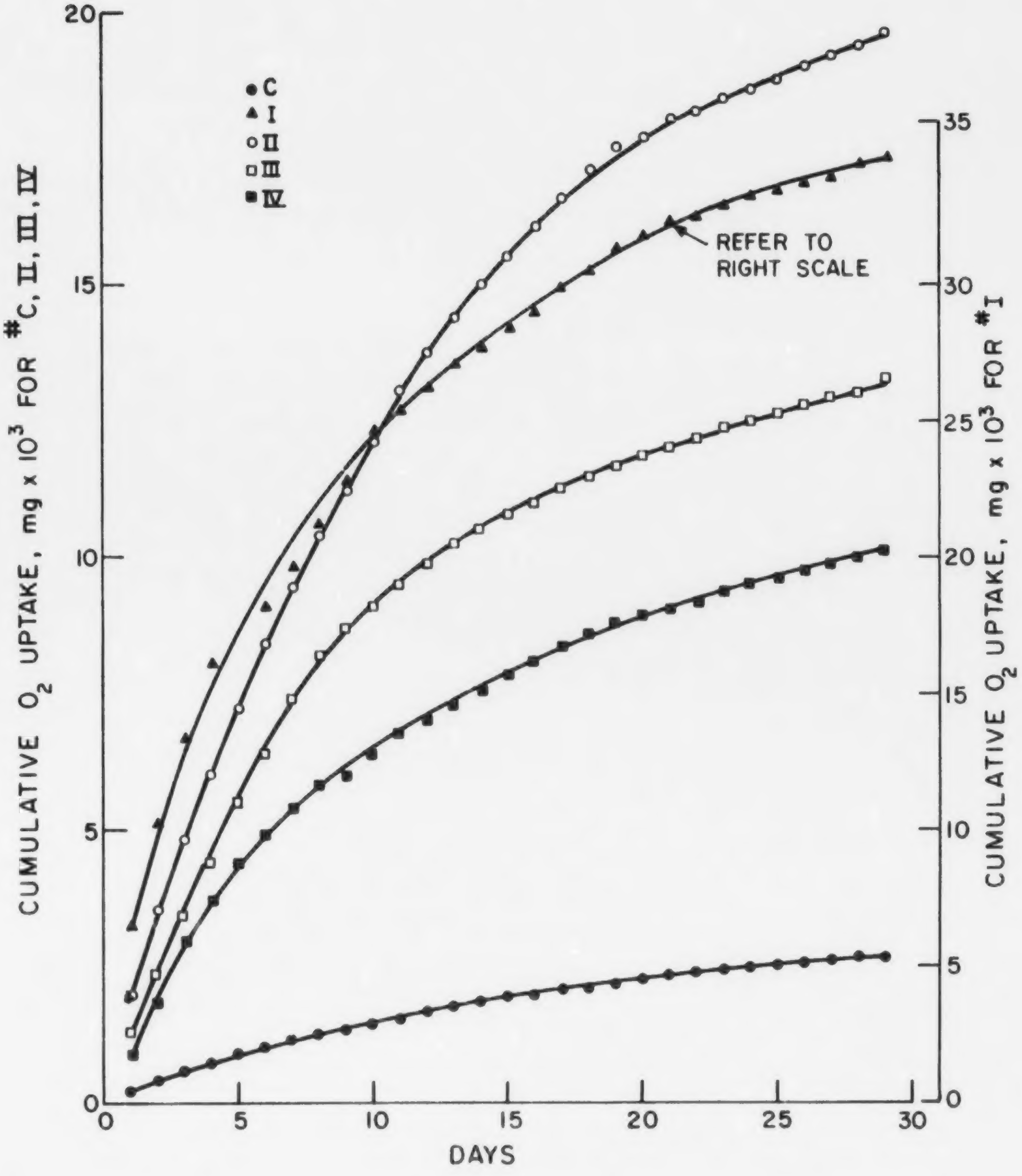


Figure 8. Cumulative oxygen uptake in the different systems during stabilization.

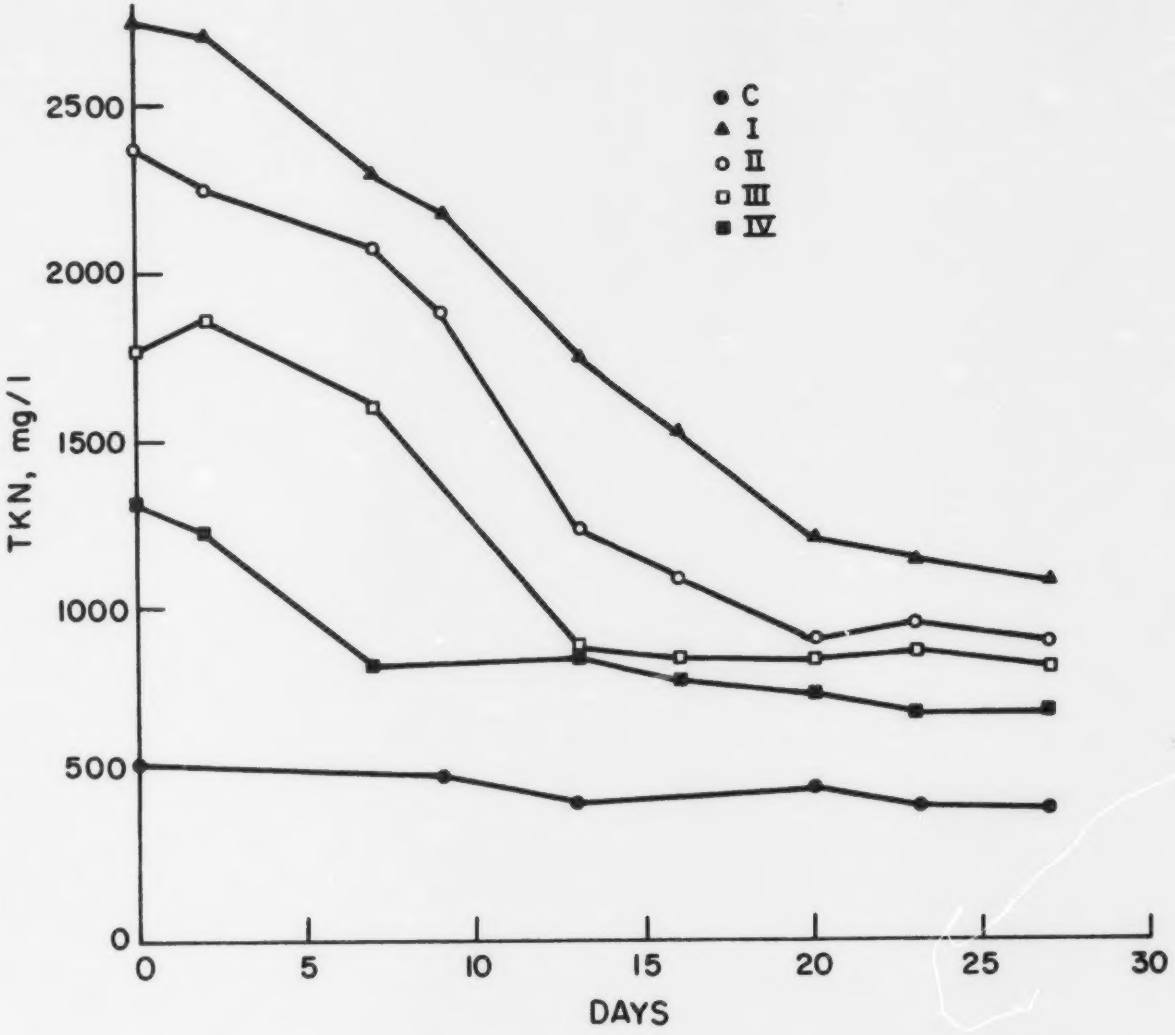


Figure 9. TKN contents of the wastes in the different systems during stabilization.

Table 10a. CUMULATIVE OXYGEN UPTAKE (COU), NITROGEN AND COD REMOVALS OBSERVED DURING STABILIZATION OF WASTES IN THE DIFFERENT SYSTEMS OF TRIAL #7

	Control			System 1			System 2			System 3			System 4		
		Removal of			Removal of			Removal of			Removal of			Removal of	
Days	COU (mg)	COD (mg)	N (mg)	COU (mg)	COD (mg)	N (mg)	COU (mg)	COD (mg)	N (mg)	COU (mg)	COD (mg)	N (mg)	COU (mg)	COD (mg)	N (mg)
1	212	0	0	6480	0	0	1944	0	0	1184	0	0	849	-	0
2	408	-	133	10295	-	458	3544	-	409	2310	-	91	1811	-	132
7	1140	-	117	21185	5754	1081	9399	6976	662	7428	1568	342	5402	8898	129
9	1350	1134	87	23863	10815	1165	11197	18494	818	8650	3662	-	6088	7328	12
13	1746	-	164	27113	-	1638	14440	-	1050	10265	-	443	7358	-	85
16	2010	-	148	29091	12439	1527	16121	20030	767	11079	4447	337	8144	8413	60
20	2264	1374	92	31927	18921	1607	17737	23131	953	11866	4347	437	8954	8362	169
23	2425	1178	156	32986	-	1443	18436	-	761	12352	7566	284	9396	10238	282
27	2608	1604	154	34180	23566	1553	19276	25596	818	12996	9677	413	9972	11517	180

Table 10b. EFFECT OF EQUILIBRIUM DISSOLVED OXYGEN CONCENTRATION AND OXYGEN UPTAKE RATE ON NITROGEN LOSS

	Control			System 1			System 2			System 3			System 4		
Days	Rr (mg/hr)	D.O. (mg/1)	N Loss (mg)	Rr (mg/hr)	D.O. (mg/1)	N Loss (mg)	Rr (mg/hr)	D.O. (mg/1)	N Loss (mg)	Rr (mg/hr)	D.O. (mg/1)	N Loss (mg)	Rr (mg/hr)	D.O. (mg/1)	N Loss (mg)
7-9	4.8	9.0	102	63.9	3.6	1123	43.2	4.9	740	35.6	5.4	342	19.1	7.6	71
16-20	3.1	9.3	120	30.1	7.1	1570	15.4	7.9	910	9.1	8.8	387	8.5	8.5	114

Operational Mode I

In this mode of operation, the oxidation ditch was operated as an aerated holding tank with continuous input of manure from the birds. The operational parameters of the ditch are given in Table 11.

Table 11. OPERATIONAL PARAMETERS OF OXIDATION DITCH - MODE OF OPERATION I

Number of birds	227
Number of days operated	276
Immersion depth of rotor	6" (15.2 cm)
Liquid volume	2000 gallons (≈7600 liters)
Liquid depth	20" (51 cm)

No odorous conditions were noted and nitrites rather than nitrates predominated during the entire period of operation. The solids accumulated to a concentration of 8.2% at which point the rotor was unable to pump the mixed liquor. Nitrification was sustained even at this concentration of solids. The nitrogen balance is presented in Table 12.

The results of this mode of operation indicated that in spite of the high dissolved oxygen concentration in the mixed liquor (>5 mg/l) and active nitrification, about 30% of the input nitrogen was lost. This loss was attributed to localized denitrification in anaerobic pockets of the mixed liquor.

Table 12. NITROGEN BALANCE - MODE OF OPERATION I

	Nitrogen, kg
Input	51.7
Accounted	31.8
Unaccounted or losses	19.9
% loss	31.1

Operational Mode II

The ditch operated as a continuous flow device with intermittent denitrification. Solids equilibrium was maintained by deliberately wasting some effluent. The operational details of the oxidation ditch in this mode of operation are given in Table 13.

As part of this mode of operation, two *in situ* denitrification studies were made in the ditch (Table 13). During these studies the rotor was stopped to achieve the losses of oxidized nitrogen. In the first denitrification phase, continuous flow operation was temporarily suspended and no overflow was permitted. The birds continued to add wastes to the ditch, thus adding an additional oxygen demand for denitrification. While the birds added wastes during the second denitrification phase, some overflow was permitted. In both studies the rotor was turned on for a portion of each day to mix the ditch contents.

Table 13. CONTINUOUS FLOW OPERATION OF THE OXIDATION DITCH WITH SOLIDS CONTROL AND WITH INTERMITTENT "IN SITU" DENITRIFICATION OF THE MIXED LIQUOR

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a) Period of operation - October 19, 1972 - April 10, 1973 (173 days)

Phases during operation	Days
1. Filling	13
2. Flow-through	69
3. *In situ* denitrification	16
4. Filling	4
5. Flow-through	64
6. *In situ* denitrification	7

b) Immersion Depth = 2" (5.1 cm)

c) Volume of oxidation ditch = 1600 gallons (6056 liters)

d) Number of birds = 250

e) Total solids concentration in the mixed liquor = 0.5%

From detailed analyses of the data, nitrogen balances were computed and the losses of nitrogen in each phase of operation of the oxidation ditch were established (Table 14). The loss of nitrogen (about 73%) observed during the initial filling period is high and may be due to: (a) ammonia volatilization which was greater when the system was restarted, (b) some

Table 14. NITROGEN LOSSES DURING DIFFERENT MODES OF OPERATION WITH SOLIDS CONTROL AND WITH INTERMITTENT "IN SITU" DENITRIFICATION

	Nitrogen Loss %[a]
Initial filling (no flow through)	73
First flow-through period	31
"In Situ" denitrification	66
Second filling period	32
Second flow-through period	29
"In Situ" denitrification	52

[a] Loss of N_2 added to the system during the mode of operation

incidental denitrification of NO_2^- and NO_3^- contained in the initial material, and (c) errors in obtaining a representative sample of the mixed liquor. Compaction of the solids in the mixed liquor took place whenever the rotor was stopped, and it was difficult to obtain a uniform sample.

In the first flow-through period the loss in nitrogen was about 31%. This was primarily due to uncontrolled denitrification even though "aerobic" conditions prevailed in the system. Ammonia volatilization was negligible. The pH of the ODML was well below 7.0 and there was active nitrification. Therefore, the losses of nitrogen observed in the system could be attributed to denitrification even though there was active nitrification in the system.

In the first controlled denitrification phase (16 days) the nitrogen loss was about 66% of the input nitrogen during that period. During this denitrification period, mixing was provided by operating the rotor for about one half hour every day. It is doubtful whether any significant part of the nitrogen input into the ditch during this period was nitrified. The losses of nitrogen input as indicated in this period only represent the loss of the nitrites and nitrates which were in the mixed liquor at the start of the denitrification period.

The nitrogen losses in the second filling period were not as high as during the first period since the ditch contents were well equilibrated and nitrification was induced rapidly due to the presence of adequate numbers of nitrifying organisms in the seed material. The nitrogen loss during this period was 32%.

The second flow-through period also showed a nitrogen loss (about 29%) which was comparable to the first flow-through period (about 31%). These losses were primarily due to uncontrolled denitrification as the pH value of the ODML was low and unfavorable for ammonia volatilization.

The nitrogen losses during the second controlled denitrification period was 52%, less than that encountered during the first denitrification period. This may be due to the lower amount of oxidized nitrogen present in the ditch during this period as compared to that of the first controlled denitrification period. Some oxidized nitrogen was lost via the effluent as the ditch was operated on a continuous flow basis during this period. The rotor was turned on for about eight hours per day during this period to provide mixing. With such an operation, the denitrification rates were higher as compared to the rates obtained during the previous controlled denitrification period when mixing of the contents of the ditch was provided by operating the rotor for one half hour daily.

Because of the difference in time periods for the denitrification periods and the regular flow-through periods of the ditch and the amount of oxidized nitrogen present, losses due to denitrification during continuous operation of the ditch were much higher than the losses achieved during deliberate denitrification. The total overall loss of nitrogen due to the deliberate denitrification in the two controlled denitrification in the two controlled denitrification stages was about 8% as compared to 23% loss attributable to uncontrolled denitrification under "aerobic"conditions, i.e., continuous operation of the rotor in the ditch. The amount of nitrogen lost during the two filling periods was 7.3% of the total nitrogen input to the oxidation ditch during the overall period. Some of this loss was due to ammonia volatilization occurring in the system when the pH value of the ODML was high. Higher pH values and NH_4^+ concentrations were observed during the filling periods than those observed during the actively nitrifying flow-through periods.

The rates of denitrification were 0.08 and 0.24 mg of oxidized nitrogen per hour per gram of total solids, respectively, during the first and second denitrification periods. Adequate mixing appears essential to achieve higher denitrification rates. The mixing did not inhibit denitrification.

A summary of the nitrogen losses over the period of the oxidation operation, (173 days), is indicated in Table 15.

During the first "flow-through" stage of the oxidation ditch, nitrification occurred. At the same time significant amounts of nitrogen were lost. This was presumably due to localized denitrification in the anoxic zones of the floc since ammonia volatilization was negligible. The probability for nitrogen loss through this mechanism may be high in a nitrifying system if the localized anoxic conditions for denitrification are increased

Table 15. NITROGEN LOSS IN OXIDATION DITCH SYSTEM[a]-
OPERATIONAL MODE II

	Percent
Total N loss during flow-through stages	23.2
Total N loss during denitrification	8.0
Total N in effluent	62.1
Total N loss during the two filling periods	7.3

[a] Expressed in terms of the overall estimated nitrogen input to the system.

while maintaining active nitrification. This may be achieved by increasing the solids concentration. Addition of raw manure will increase both the suspended solids content and the oxygen demand of the system and increase the probability of anoxic conditions in the microbial floc as a result of increased concentration of particulate matter and decreased oxygen transfer. Under these circumstances, the probability for denitrification of NO_2^- and NO_3^- will increase.

Operational Mode III

During this phase of operation attempts were made to control the solids content of the ODML without adding fresh water. The mixed liquor from the oxidation ditch was pumped intermittently into a settling tank. The mixed liquor was settled and the supernatant liquid was returned to the ditch. Some make-up water, approximately 25 gallons per week during summer months occasionally was added to compensate for the losses due to evaporation. No water was added during the winter.

After the initial period during which the detention time in the settling tank was variable, a detention time of 8.5 days was maintained. Two hundred gallons of sludge that accumulated in the settling tank were periodically wasted every 3 to 4 weeks by opening a valve located at the bottom of the settling tank.

In addition to monitoring the total solids content, chemical analyses of the mixed liquor from the ditch, and the supernatant and the wasted sludge from the settling tank were made on a regular basis. From this data, nitrogen balances were computed.

The operational parameters for this mode of operation are presented in Table 16 with the results of the nitrogen balance in Table 17.

Table 16. OPERATIONAL PARAMETERS OF OXIDATION DITCH - OPERATIONAL MODE III

Number of birds = 226
Number of days = 99
Immersion depth of rotor, liters = 5.2 (2")
Liquid volume, liters = 6056 (1600 gallons)
Volume of settling tank, liters = 1685 (455 gallons)
Detention time in settling tank = 8.5 days
Total solids in ODML = ≈1.3%

Table 17. TOTAL NITROGEN BALANCE IN OPERATIONAL MODE III

a) Total nitrogen (TN) losses from the oxidation ditch - settling tank system:

TN input to system = 42.04 kg
ΔTN in oxidation ditch = 0.65 kg
TN in wasted sludge = 7.37 kg
ΔTN in supernatant = 0.11 kg

$$\begin{aligned} \text{TN losses} &= \text{TN input} - \Delta\text{TN in ditch} - \text{TN in sludge} - \Delta\text{TN in supernatant} \\ &= 42.04 - 0.65 - 7.37 - 0.11 = 33.91 \text{ kg} \end{aligned}$$

$$\%\ \text{TN losses} = \frac{33.91}{42.04} \times 100 = 80.6$$

b) Total nitrogen loss accomplished in settling tank:

$$\begin{aligned} \text{TN losses in settling tank} &= \text{TN input to settling tank} - \text{TN in wasted sludge} - \Delta\text{TN in supernatant} \\ &= 11.62 - 7.37 - 0.11 = 4.14 \text{ kg} \end{aligned}$$

$$\%\ \text{TN loss due to denitrification in settling tank} = \frac{4.14 \times 100}{42.04} = 9.8$$

c) TN loss in oxidation ditch = 80.6 - 9.8 = 70.8%

The results of this mode of operation indicated that significant losses of nitrogen from the system can be achieved by recycling the mixed liquor through a settling tank. About 10% of the total nitrogen input from the birds was removed in the settling tank while a major portion, about 70%, was removed in the oxidation ditch. These losses in the ditch were significantly higher than the 30% of losses generally observed in the ditch when it was operated without the recycling of mixed liquor. These increased losses in nitrogen in this mode of operation may be due to (a) seeding of the ditch by a highly efficient denitrifying population which is carried over by recycling the supernatant, and (b) the very long hydraulic detention time provided for the nitrate containing supernatant fraction of the mixed liquor due to recycling to the ditch.

The above summary identifies the TN losses from the entire system. The loss of nitrogen due to the settling tank also was computed. The total nitrogen and NO_2^- plus NO_3-N profiles for the ODML entering and the supernatant leaving the settling tank are presented in Fig. 10 and 11. These patterns and the data collected on the wasted sludge indicate that a significant portion of TN entering the settling tank from the oxidation ditch was removed due to settling and denitrification. The losses of the total nitrogen entering the settling tank due to denitrification amounted to about 36%, while 63% of the TN loss was removed in the sludge. However, the total nitrogen removal in the settling tank represnted only 10% of the total input nitrogen from the birds.

Operational Mode IV

In the previous modes of operation, aeration was provided by operating the rotor continuously. In this mode the effect of curtailing the rotor aeration on nitrogen losses was studied. Such an operation should provide an opportunity for the mixed liquor to denitrify in the ditch without the aid of a

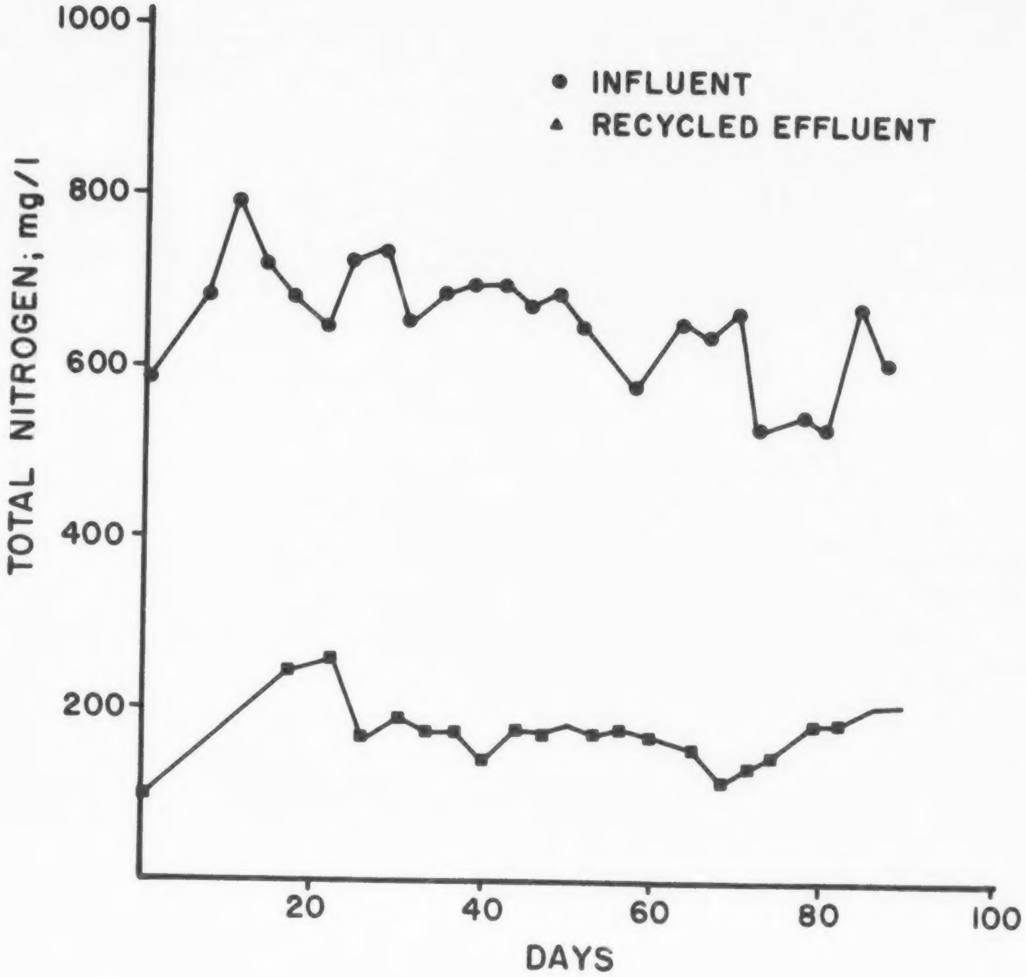

Figure 10. Total nitrogen profile of the influent and effluent of settling tank - June 6 - September 13, 1973.

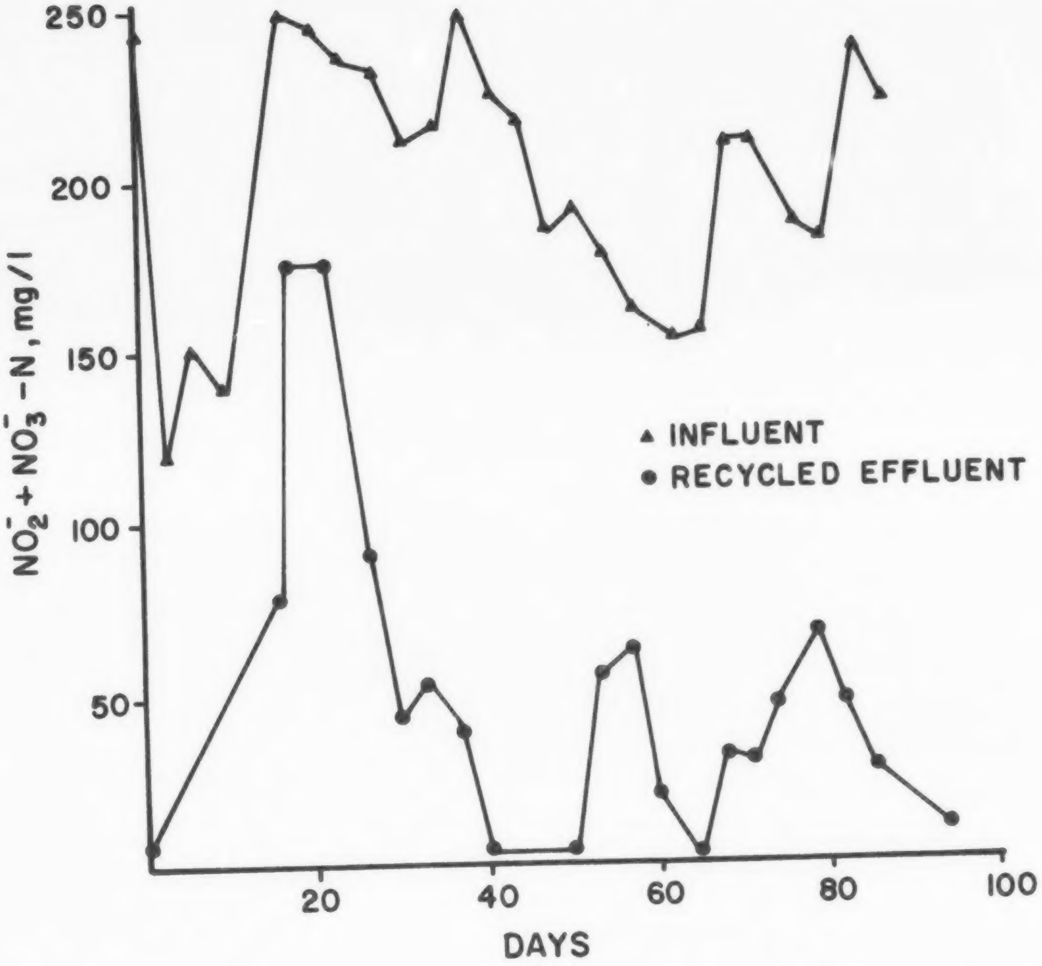

Figure 11. Oxidized nitrogen profiles of influent and effluent of settling tank - June 6 - September 13, 1973.

settling-denitrification tank. Some savings in power consumption may be realized by turning off the rotor.

During this mode the rotor was connected via a time switch to the power line. The switch was adjusted to a predetermined time interval and controlled the period of aeration by the rotor. Two experimental runs were made in which the rotor was operated for 16 and 12 hours per day respectively. Each experimental run lasted for about three weeks. Wastes from the birds were added continuously. The ditch was operated as an aerated holding tank with no overflow. Analyses for total solids, TKN, NO_2-N, NO_3-N, NH_4-N and COD were performed routinely. The nitrogen balances are presented in Tables 18 and 19.

The results of this study indicated that it was possible to remove up to 90% of the total nitrogen input to the oxidation ditch by manipulating the aeration period. When the rotor was operated for 12 hr/day, larger nitrogen losses were observed than when the rotor was operated for 16 hr/day. From the profiles of oxidized nitrogen concentration of the mixed liquor at the above periods of rotor operation (Fig. 12), the NO_3-N concentration progressively decreased in the mixed liquor when the aeration period was 12 hr/day, whereas it was relatively constant when the period of aeration was 16 hr/day. In both instances the pH of the mixed liquor was near neutral suggesting that the nitrogen losses were not due to ammonia volatilization and primarily were due to a nitrification-denitrification mechanism.

The observed total nitrogen loss coupled with the progressive decrease and the eventual disappearance of mixed liquor NO_3-N concentration in the 12 hour mode of rotor operation suggested that the extent of denitrification exceeded that of nitrification. However, in the 16 hour mode of rotor operation, the mixed liquor NO_3-N concentration remained relatively

Table 18. NITROGEN BALANCE IN AN OXIDATION DITCH - OPERATIONAL MODE IV (ROTOR ON FOR 16 HOUR/DAY[a])

Days	Cumulative TN input (kg)	% TN loss
0	-	-
2	1.1	34.5
6	3.3	49.3
9	4.9	51.1
13	7.2	53.6
16	8.8	58.2
20	11.0	62.5
23	12.7	69.6

[a] Amount of oxidized nitrogen left in ODML = 2.7 kg

Table 19. NITROGEN BALANCE IN AN OXIDATION DITCH - OPERATIONAL MODE IV (ROTOR ON FOR 12 HOUR/DAY[a])

Days	Cumulative TN input (kg)	% TN loss
0	-	-
4	2.1	44.4
7	3.7	82.6
11	5.9	91.3
14	7.5	95.2
18	9.6	92.5
21	11.2	88.3

[a] Amount of oxidized nitrogen left in ODML = 0 kg

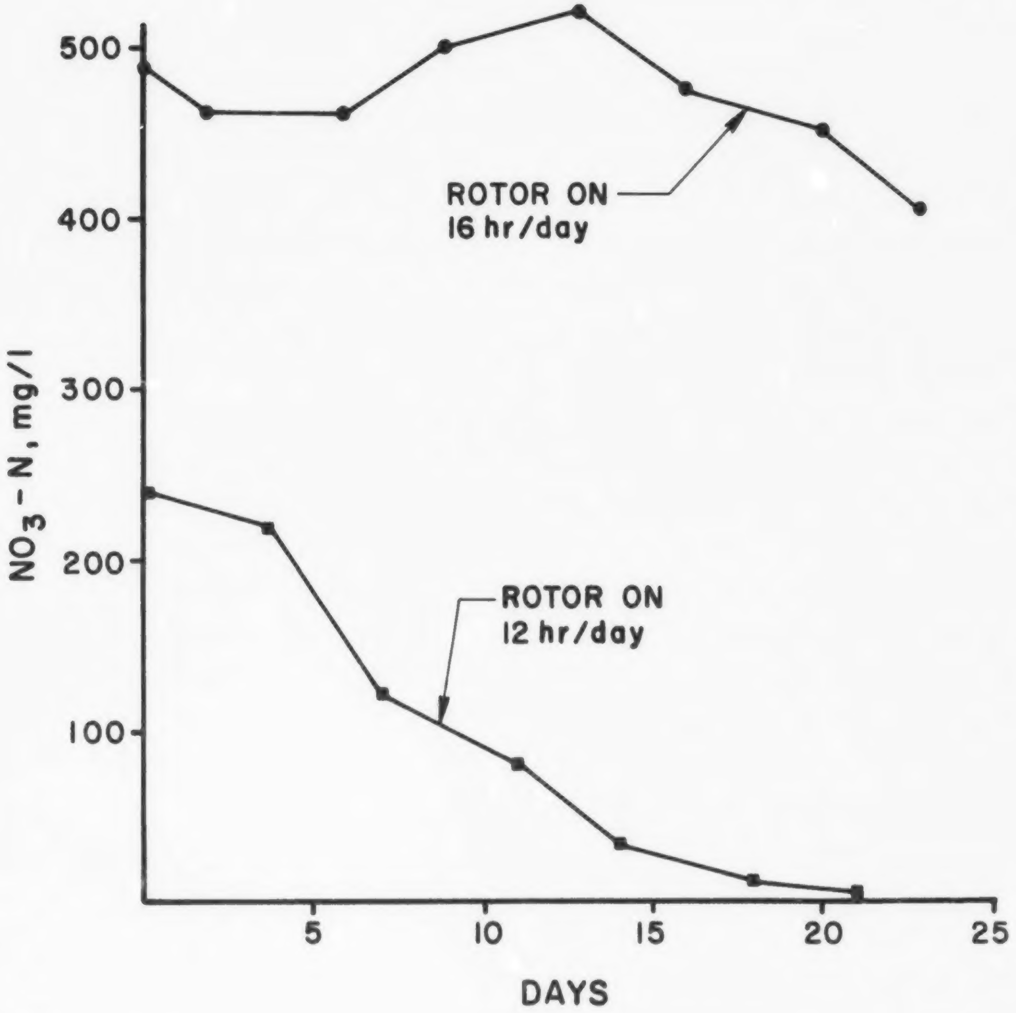

Figure 12. Profile of NO_3-N in ODML - operational mode IV.

constant at 450 mg/l suggesting that the extent of nitrification was not less than that of denitrification. If the remaining NO_3-N were denitrified subsequently, the total nitrogen losses would amount to about 90% and would be comparable to the nitrogen losses observed when the ditch was aerated 12 hrs/day.

There appears to be an optimum period of aeration between 12 and 16 hrs/day for this system at which the extent of nitrification equals that of denitrification. If the mixed liquor is aerated for such a period in a day, then it would be possible to achieve no accumulation of oxidized nitrogen, while maintaining odorless conditions and accomplishing high nitrogen removals without the aid of additional units for separate denitrification.

FULL SCALE OXIDATION DITCH SYSTEMS

Houghton Operation

In early 1972, a full scale oxidation ditch stabilization system was installed in a nearby poultry farm. The system was put in by the owner, Mr. C. L. Houghton, after he had seen the pilot plant oxidation ditch at Cornell University. Prior to the installation of the oxidation ditches, the waste handling on the farm consisted of liquid collection and anaerobic storage in pits located under the cages. The oxidation ditches in this operation were formed by connecting both ends of a pair of manure collection pits. Following the installation of the system, personnel of the Department of Agricultural Engineering at Cornell have worked closely with Mr. Houghton to monitor the system and cause it to operate satisfactorily. The results of observation made during 1972 have been described in the earlier report to the EPA (5).

The objective of the stabilization system in this operation is odor control. Attempts have been made to assess the performance of the system as a nitrogen control device under these conditions of operation. The oxidation ditch system is operated as an aerated holding tank. The cages are above the ditches and input of manure to the stabilization system is continuous. The large amount of water leakage from the dew drop watering system necessitates the periodical removal of the mixed liquor from the ditches. Foaming is controlled by addition of motor oil to the mixed liquor.

Variations in factors such as quantity and frequency of removal of the mixed liquor from the ditches resulted in solids retention times ranging from 12 to 36 days and permitted the evaluation of the effects of varying detention times and other operational conditions on the performance of the system.

Throughout this study period, estimates of daily loading of total nitrogen, solids, and COD were made by analyzing 24 hour composite samples of bird excreta. Samples of mixed liquor were routinely collected and analyzed for the total solids content, COD and the different forms of nitrogen.

Mass balances were made to determine (a) the efficiency of nitrogen and COD removals, and (b) the extent of conversion of organic nitrogen to other forms.

Throughout this study, the stabilization systems have achieved their objective of odor control. The total nitrogen input to the system varied from 1012 to 1430 kg per month. The extent of the removal of nitrogen and COD varied from 29 to 53, and 26 to 59 percent respectively. The total nitrogen input to the system and the quantities of nitrogen accounted for during the eleven month period are shown in Figure 13.

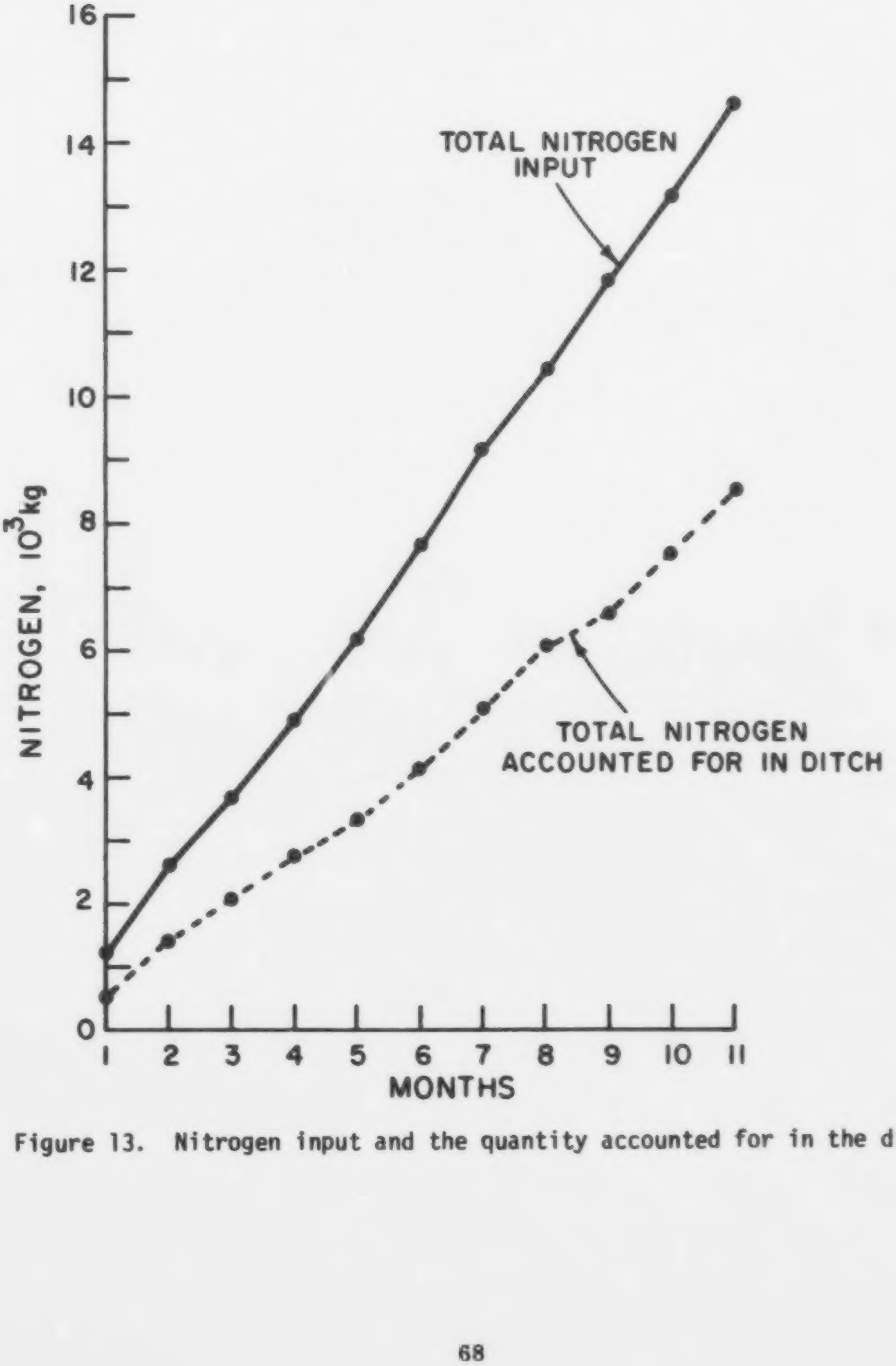

Figure 13. Nitrogen input and the quantity accounted for in the ditch.

The pH value of the mixed liquor was always alkaline. Except for a short period in October 1972, when the pH was in the range of 7.6 to 7.9 and nitrites were present in the mixed liquor, the pH value of the liquor was in the range of 8.1 to 8.4. Oxygen input to the system was insufficient to maintain a residual dissolved oxygen throughout the length of the channel. Therefore, the nitrogen removals from the system were largely due to ammonia volatilization. The concentration of ammoniacal nitrogen fell sharply in the month of October. The losses in nitrogen during this period, when nitrification was also noted, were due to ammonia volatilization and denitrification of the oxidized nitrogen compounds.

The analytical data were further evaluated to develop predictive relationships between manurial nitrogen inputs to the ditches, nitrogen contents of ODML, and losses of nitrogen due to ammonia desorption. The total numbers of birds in the operation, the loadings, the average concentrations of NH_4^+-N during the different months of operation, and other details relating to this study are given in Table 20. The total number of birds was fairly constant. Fluctuations in the NH_4^+-N concentration during each of the months of April, May, June, July, August and September, were minimal. However, the total volume of ODML of the systems changed due to changes made in the operation of the oxidation ditches.

If A is the rate of addition of manurial nitrogen to the oxidation ditch, and 50% of the nitrogen in the poultry excreta is easily convertible to NH_4^+, then the rate of NH_4^+ input to the system is A/2.

If V is volume of ODML in the system, the rate of increase in the concentration of NH_4^+-N is A/2V.

Let ΔC = change in NH_4^+-N concentration during Δt (11)

$$= \frac{A}{2V} \cdot \Delta t - K_D \cdot F \cdot C \cdot \Delta t$$

Table 20. INPUTS TO THE OXIDATION DITCHES, MEAN CONCENTRATIONS OF AMMONIACAL NITROGEN, pH, AND TEMPERATURE OF ODML AT THE HOUGHTON FARMS

Month	Inputs to the ditches				ODML				
	Number of birds	Total Solids (kg)	COD (kg)	TKN (kg)	Volume (liters)	Liquid Depth (inches)	Conc. of NH_4-N (mg/l)	pH	Temp. °C
February	14,259	15,366	11,950	1,294	110,576	18	2,457	8.5	15
March	14,114	16,259	12,775	1,370	109,367	18	2,436	8.4	16
April	14,062	12,019	9,347	1,012	198,308	32	1,560	8.2	20
May	12,395	14,279	11,105	1,203	194,810	32	1,782	8.3	24
June	14,777	16,473	12,812	1,388	204,730	33	1,596	8.2	27
July	14,655	16,882	13,129	1,422	213,604	35	1,266	8.2	28
August	14,533	16,741	13,020	1,410	212,395	35	1,137	8.2	25
September	14,450	16,109	12,528	1,357	211,628	35	1,054	8.1	23
October	13,850	15,955	12,082	1,344	213,040	36	472	7.6	17
November	14,855	16,560	12,879	1,395	212,878	36	812	7.9	18
December	14,740	16,980	13,206	1,430	199,570	33	1,181	8.1	19

where K_D is the ammonia desorption coefficient for the oxidation ditch system;

F is the fraction of ammoniacal nitrogen in ODML available for desorption. F is dependent upon pH and temperature. $F = 10^{pH}/[K_b/K_w + 10^{pH}]$ where K_b and K_w are the dissociation constants of ammonia and water, respectively; and their values are dependent upon temperature.

C is the concentration of ammoniacal nitrogen in the ODML.

When the system has reached a steady state,

$$\frac{A}{2V} = K_D \cdot F \cdot C \qquad (12)$$

Therefore,

$$K_D = \frac{A}{2VFC} \qquad (13)$$

The desorption of ammonia in the oxidation ditch system occurs from the entire surface area of the liquid exposed. However, strong smell of ammonia gas was always found near the rotors. In comparison to the ammonia losses occurring in the channels, the losses near the rotor are large. The ammonia desorption occurring in the oxidation ditch could be considered as almost entirely due to the action of rotors. The extent of liquid-air contact area created by a rotor is largely dependent on the design and on the rotor immersion depth and speed (RPM). When rotors of same design are operated under similar conditions of immersion depth and speed, the extent of surface renewal occurring in the system are proportional to the length of the rotor. Therefore, an ammonia desorption rate that is characteristic of the rotor could be calculated in a manner similar to the oxygen input capacity of the rotor. The available data related to the operation of the rotors at only one immersion depth and based on this information, the K_D value of the rotors was found to be 0.00584 per hr per ft of the rotor. More evidence is necessary to find the value of K_D at other rotor immersion depths.

With the value of K_D for the rotor known, estimates of losses due to ammonia volatilization can be calculated. If nitrogen losses in the system are only due to ammonia volatilization, and the system has reached a steady state condition, it is possible to calculate the inputs of nitrogen to the system. The quantity of nitrogen actually entering the system, and the estimates of nitrogen inputs based on the use of Equation 11, are shown in Figure 14. These results indicated that the estimates of nitrogen input show some agreement with the actual nitrogen inputs except in those months where some degree of nitrification occurred (September, October, and November).

Manorcrest Farms

The two oxidation ditches in this operation are installed beneath the caged laying hens, and each receives the wastes from 4,000 birds. The mode of operation of these ditches can be described as continuous flow operation with supernatant recycle from the settling tanks. The stabilization systems have effectively functioned as an odor control device since their installation in August 1973. The aeration devices installed for the ditches are different in their design and oxygenation capacities. The rotor providing oxygen to ditch no. 1 is of the conventional cage-type rotor design. The rotor providing oxygen to ditch no. 2 is a brush aerator. The oxygen input by the conventional rotor is much higher than the brush aerator.

Twenty-four hour composite samples of bird excreta, samples of mixed liquor, and supernatant liquors returning to the ditches were analyzed for forms of nitrogen and COD. Mass balances were computed to assess the performance of the ditches as nitrogen control systems.

A high degree of nitrification was noted (Fig. 15) and there were no ammonia odors in the poultry houses after nitrification had set in the system.

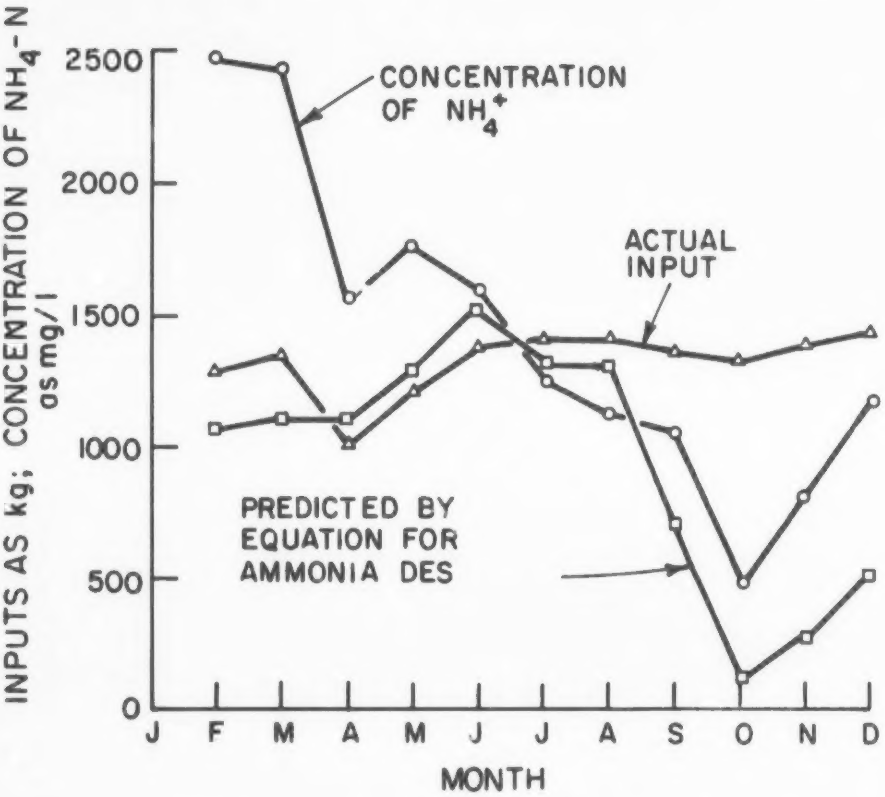

Figure 14. Actual quantity vs. nitrogen estimates.

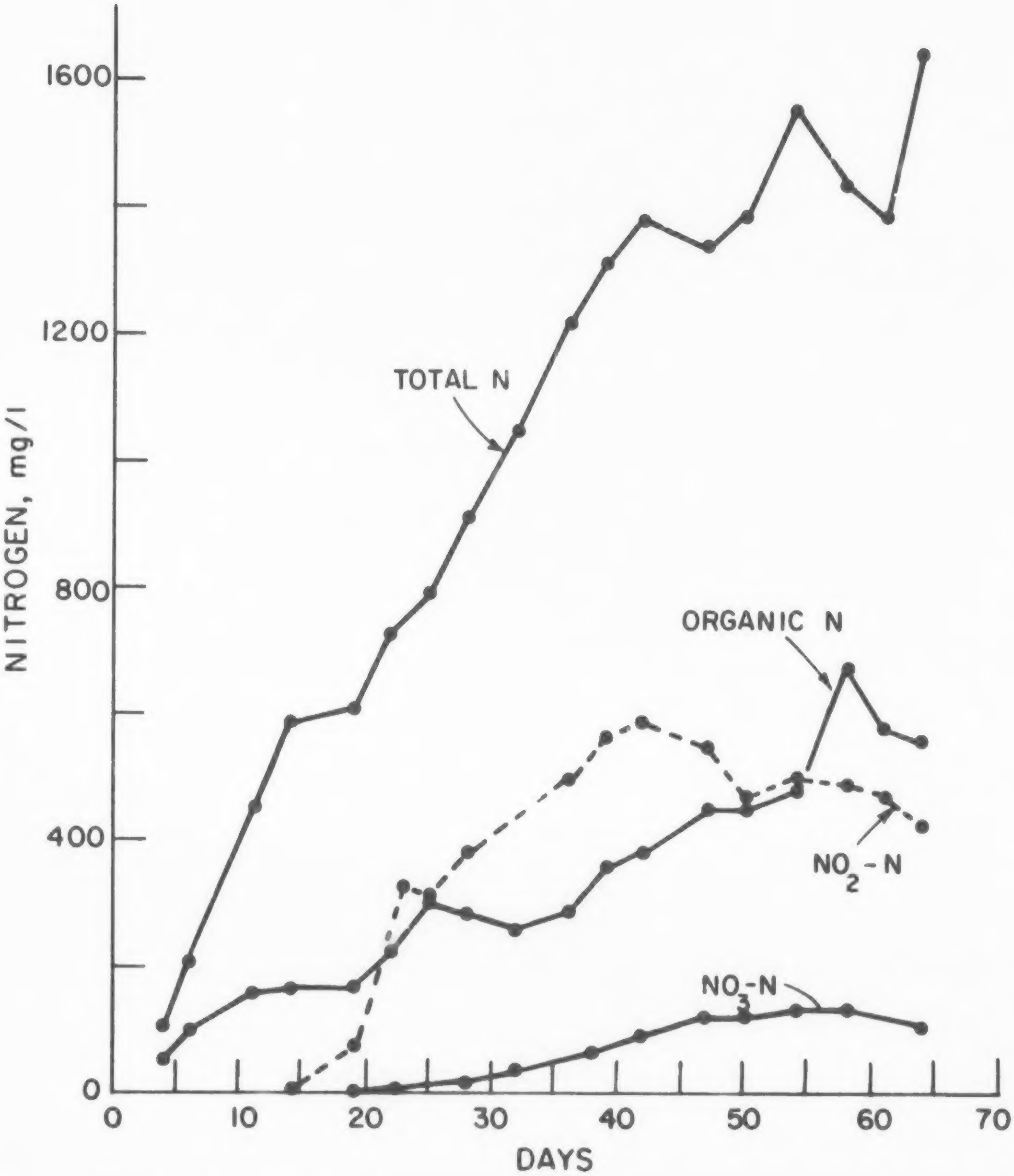

Figure 15. Effect of operation of oxidation ditch on nitrification.

Figures 16 and 17 show the fluctuations in the concentrations of the different forms of nitrogen after the systems had reached steady state. Even though about 70% of the organic nitrogen in the manure was converted to ammonium, only small amounts of nitrites and nitrates were observed. The presence of low levels of nitrites and nitrates suggested (a) that denitrification was also occurring in the systems; and (b) that the input of oxygen was insufficient to provide a residual dissolved oxygen concentration in the ditch to prevent the nitrogen losses due to denitrification.

The profiles of the expected and the observed total nitrogen concentrations in the mixed liquors in the ditches over a period of two months are shown in Figures 18 and 19. The mass balances for nitrogen indicate that about 65% of the nitrogen added to the ditches was lost due to the mechanisms of simultaneous nitrification and denitrification occurring in the system.

Oxidation Ditch at the Mink Farm

Experiences in the operation of oxidation ditches to handle poultry wastes provided basic information on nitrogen control and factors influencing oxygenation of highly concentrated wastes. In aerobic biological stabilization units with long detention times, the largest portion of the energy input is utilized to overcome the inertia of any rotor or surface aerator and to mix the contents of the unit. With the background of the experiences gained in operating an oxidation ditch, a Jet-Aero-Mix system of aeration was designed and installed to treat the wastes from the experimental mink farm (18). From a general maintenance standpoint, this system does not have the problems of bearings and belt slippage associated with rotor systems.

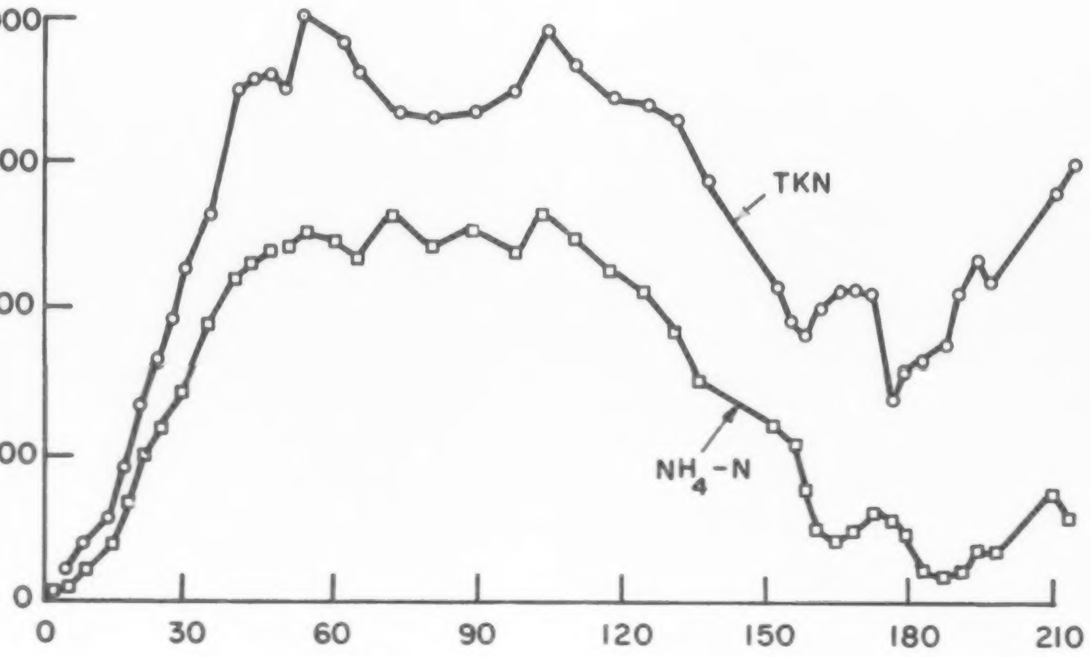

Figure 16. Fluctuations in nitrogen contents of mixed liquor in oxidation ditch #1 at Manorcrest Farms.

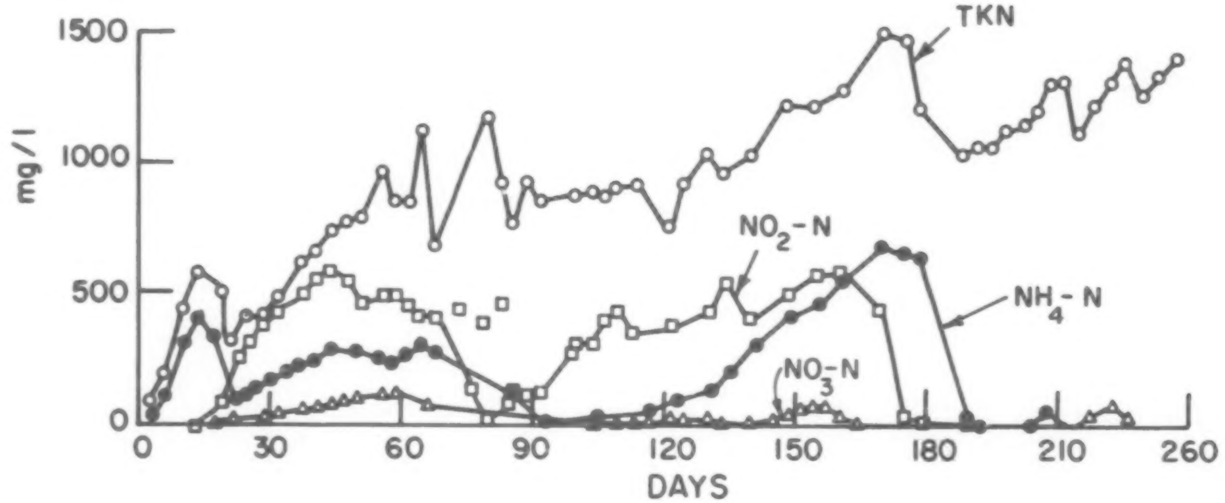

Figure 17. Fluctuations in nitrogen contents of mixed liquor in oxidation ditch #2 at Manorcrest Farms.

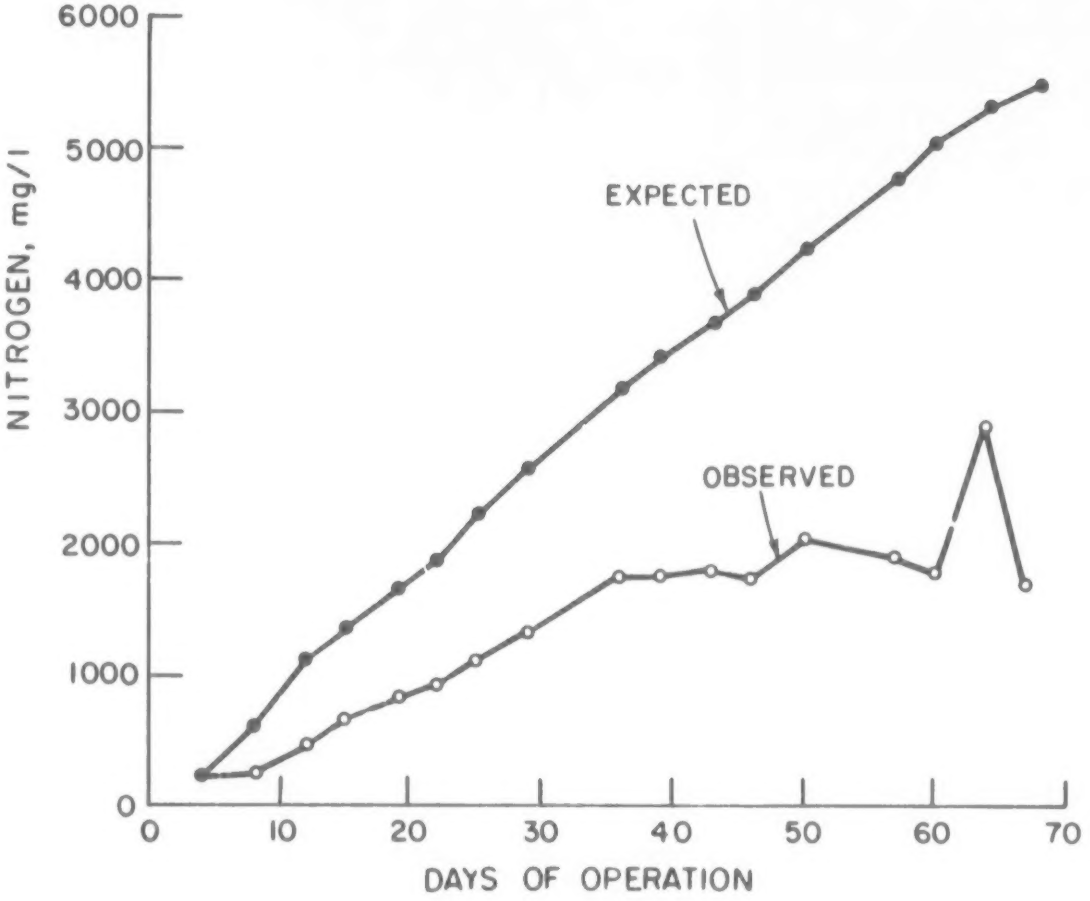

Figure 18. Expected and observed total nitrogen contents of mixed liquor in oxidation ditch #1 at Manorcrest Farms.

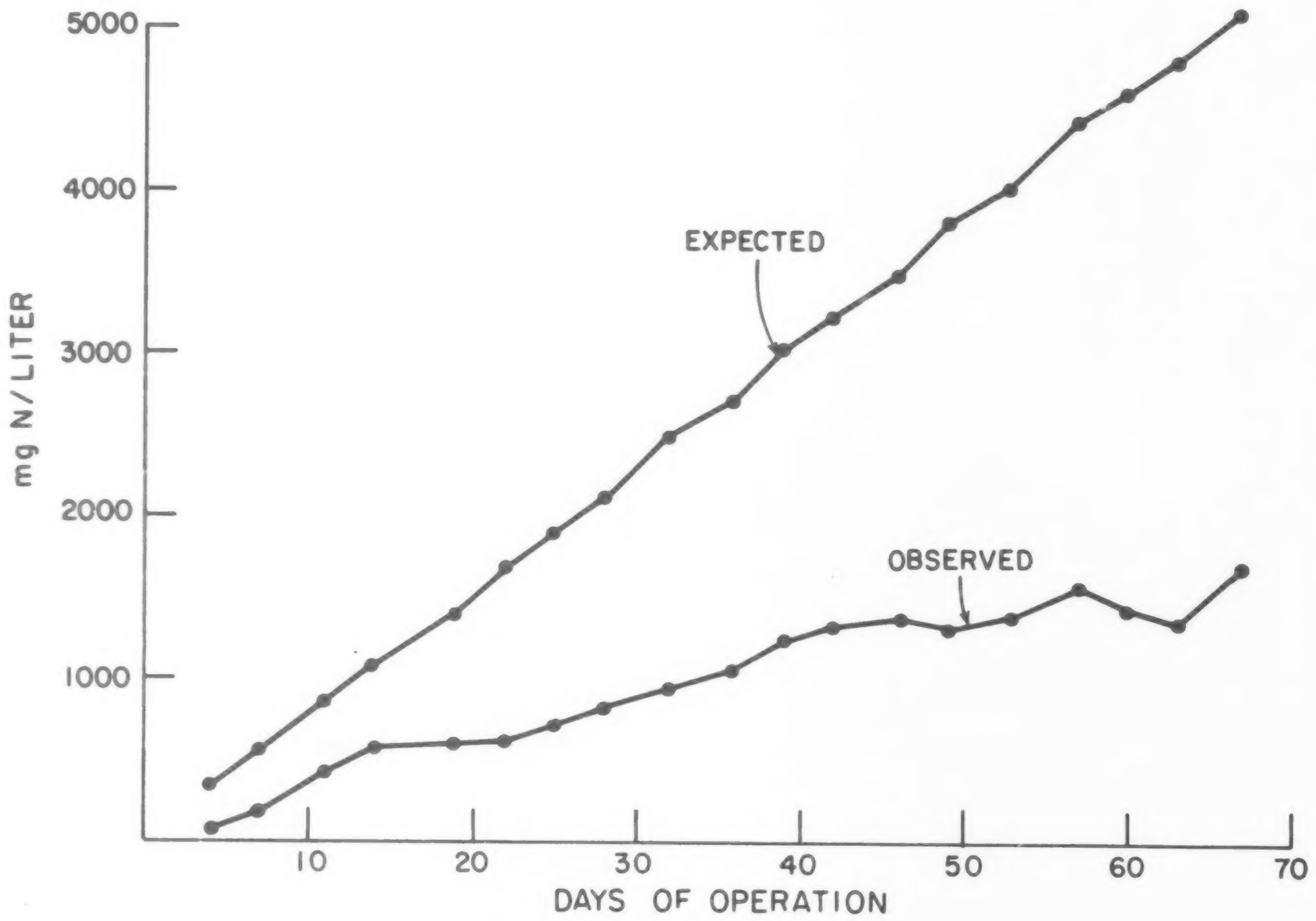

Figure 19. Expected and observed total nitrogen contents of mixed liquor in oxidation ditch #1 at Manorcrest Farms.

The observations on this treatment system indicated that liquid aeration systems could easily be incorporated beneath confined minks and the offensive odors from the manure could be eliminated. The oxygen input to the system was adequate for both odor control and nitrogen conservation. The characteristics of the mixed liquor examined over a period of six months are given in Table 21.

The nitrates accumulating in the system could be removed by stopping aeration and allowing the liquor to denitrify. Mass balances computed to assess the treatment efficiencies indicated that the system was capable of removals of about 93, 97, and 46 percent, respectively, of nitrogen, BOD and total solids.

Table 21. CHARACTERISTICS OF THE MIXED LIQUOR FROM THE OXIDATION DITCH AT THE MINK FARM

Date	Total Solids (mg/1)	COD (mg/1)	TKN (mg/1)	NH_4-N (mg/1)	NO_2-N (mg/1)	NO_3-N (mg/1)	pH
16 Nov. 1973	2,350	585	99.4	54.6	7.2	42	7.3
23 Nov. 1973	3,600	-	108.5	46.9	11.5	165	5.6
30 Nov. 1973	4,550	1,791	198.8	114.1	0.6	240	5.6
8 Dec. 1973	3,673	2,534	78.7	trace	trace	520	7.5
14 Dec. 1973	7,500	3,030	179.0	6.3	trace	650	5.6
21 Dec. 1973	9,200	3,149	136.0	0	trace	650	6.2
28 Dec. 1973	10,135	2,938	123.0	11.2	trace	800	6.0
4 Jan. 1974	11,918	3,256	126.0	21.0	1.3	950	6.5
11 Jan. 1974	12,818	4,177	154.0	14.7	0.3	1,300	6.5
18 Jan. 1974	-	4,739	160.0	9.8	0.3	1,300	6.0
25 Jan. 1974	15,840	5,491	118.0	0	0.3	1,700	6.8
6 Feb. 1974	-	-	100.8	trace	trace	1,800	8.0
8 Feb. 1974	19,230	5,860	237.0	96.6	trace	1,750	7.8
22 Feb. 1974	21,300	5,785	277.0	70.7	trace	2,150	5.7
1 Mar. 1974	22,905	8,058	195.0	9.8	trace	2,150	5.7
4 Mar. 1974	23,588	9,172	209.0	14.0	trace	2,250	5.8
8 Mar. 1974	24,748	8,264	210.0	1.4	trace	2,150	6.6

SECTION V

RESULTS OF STUDIES ON LAND APPLICATION OF POULTRY WASTES

APPLICATION RATES AND NITRATE LEVELS IN THE SOILS

Soil nitrate levels as influenced by rate of N application at the three corn locations and one grass location were determined. Values for the surface soil are presented in Figure 20 and subsurface values in Figure 21. A higher nitrate concentration resulted with increasing rates of manure application in both surface soils and subsoils. Surface soil nitrate levels were higher than subsoil nitrate levels at a given rate of application. Although the values presented in Figures 20 and 21 are averages for the 1973 growing season at all locations, they do indicate that nitrates tend to be concentrated in the surface layer and that the surface layer of soil contains a concentration of nitrates about twice that of the subsoil for a given rate of application. Higher nitrate levels were maintained under the corn plots than under the grass. This suggests that grasses are heavier feeders on soil nitrates and will result in lower soil nitrate levels at all rates of application in both the surface soil and subsoil.

This would seem to indicate that grasses could tolerate application rates higher than 200 pounds N equivalent of poultry waste. This may be true of oxidation ditch manure which is high in water content and therefore would distribute the manure salts deeper and more uniformly through the soil

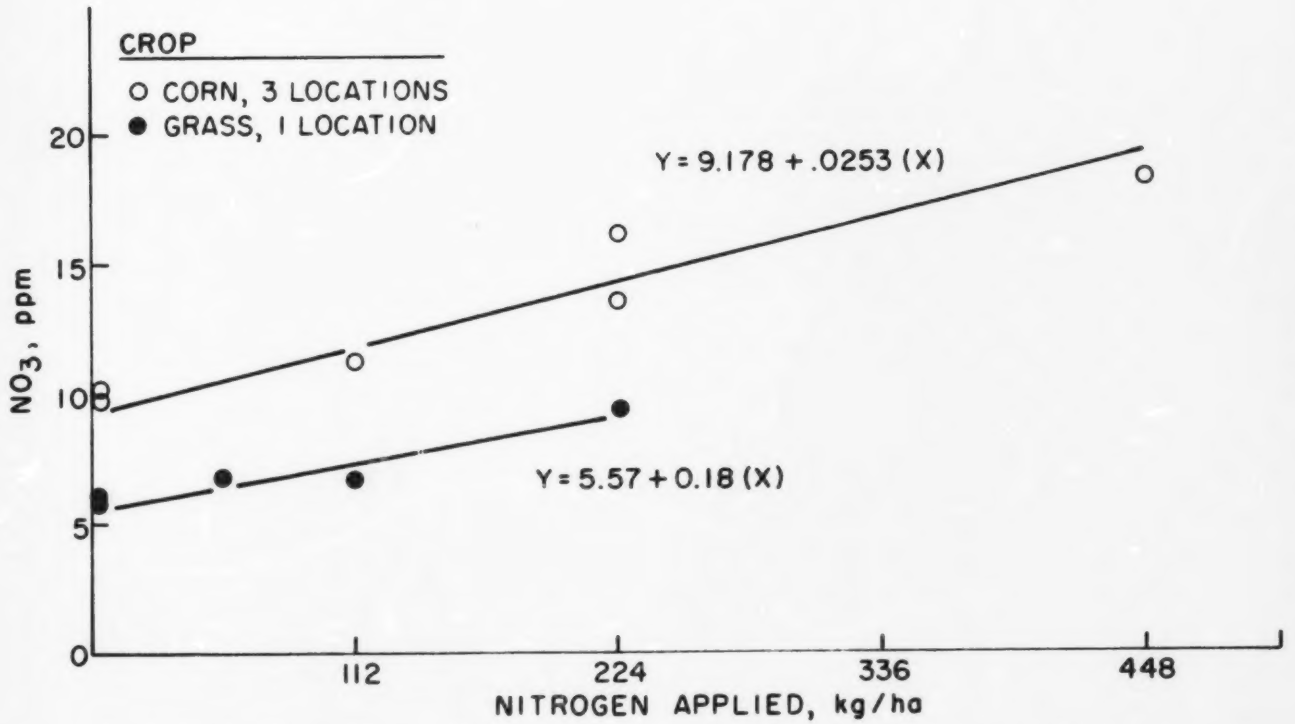

Figure 20. Average growing season NO_3 level in the surface soil 0-23 cm as influenced by several rates of spring applied ODML on corn and grass, 1973. Average of four studies.

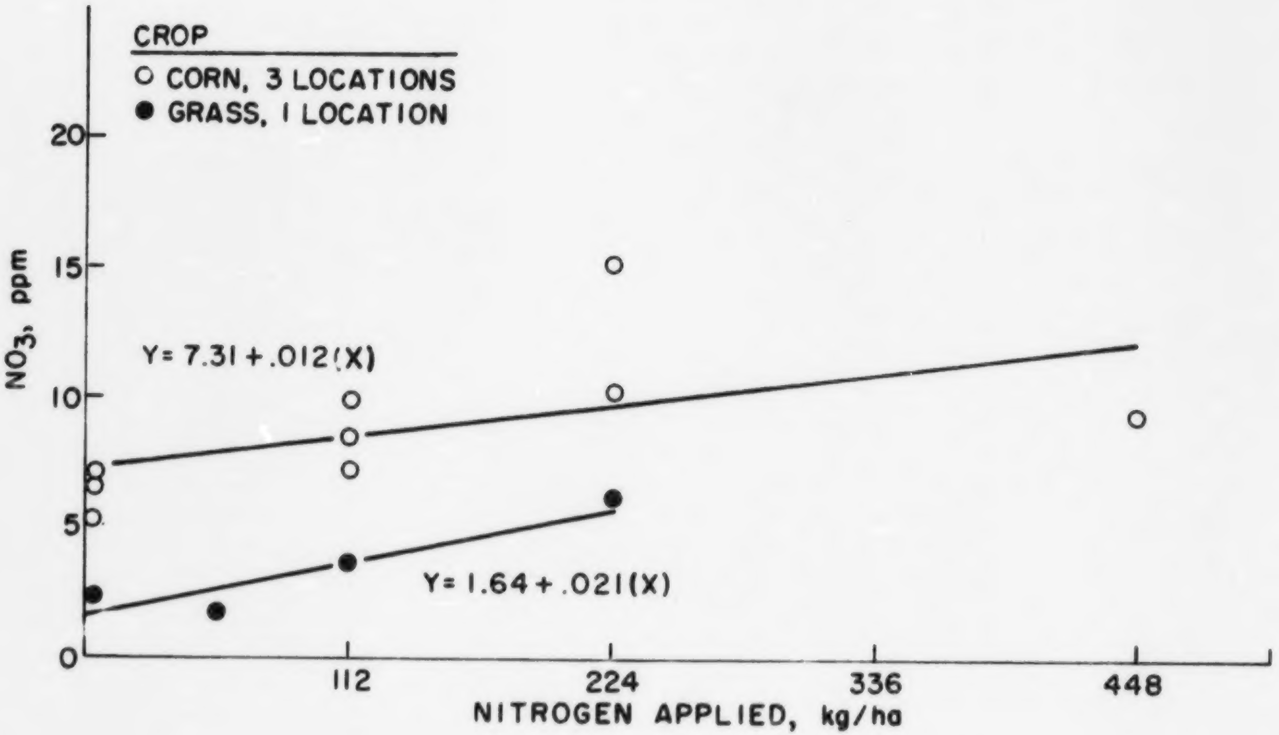

Figure 21. Average growing season NO_3 levels in the subsoil, 24-46 cm, as influenced by several rates of spring applied ODML on corn and grass, 1973. Average of four studies.

profile. However, since plowing or soil incorporation is not the practice with grass sods other forms of poultry wastes would not move readily into the soil and would result in too high concentrations of salts in intimate contact with the above-ground portion of grasses. This could result in injury or death of the plant.

Nitrate levels in both the surface soil and subsoil fluctuate throughout the growing season (Fig. 22). Values under both corn and grass are shown. Again, nitrate levels in the soil under grass are lower than those under corn. Values are higher during June and July in the surface soil. This is not surprising because soil conditions, especially moisture and temperature, were favorable for mineralization of N. Subsoil nitrate levels were highest in June under corn. This is explained by the fact that soil conditions favored mineralization of N and that the corn plants were young and absorbing small quantities of N. Rainfall during the period of rapid N mineralization and low plant uptake of N can result in rapid downward movement of nitrates into the subsoil. Although it is difficult to predict exact mineralization rates of N from manure, generalizations can be made regarding safe application rates (19).

SURFACE RUNOFF LOSS, FIELD STUDIES

The bar graphs in Figures 23 and 24 show average growing season nitrate and ammonium values in surface soil and subsoil as influenced by source, rate of application and Spring vs. Fall application. Data are presented in these figures from the two locations, Poultry Farm and Aurora Research Farm. Nitrate levels in the surface soil and subsoil increased with increasing rates of poultry manure. Higher levels were recorded with Spring applications of both fresh and oxidation ditch poultry manure than with these materials applied in the Fall. This suggests that nitrates have been lost from the Fall applied material. In addition, these nitrates

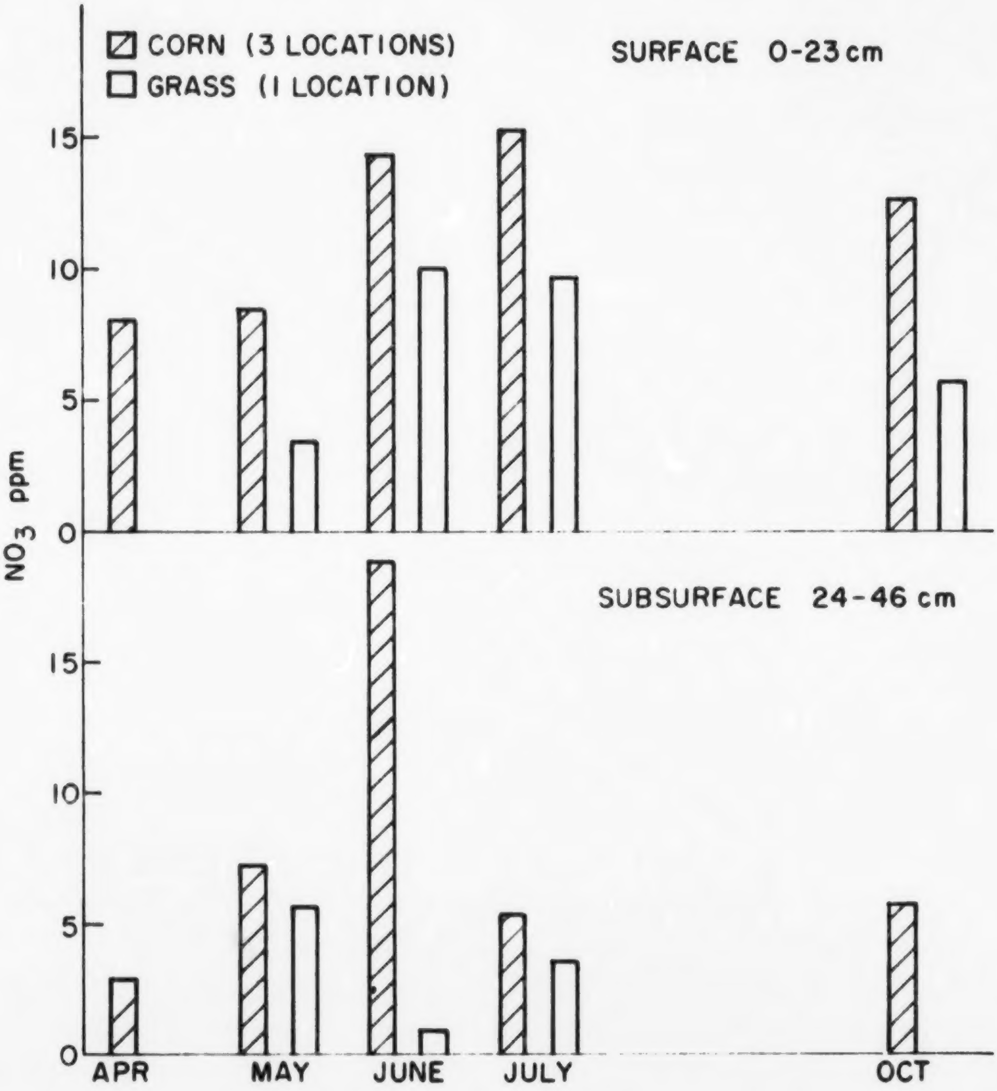

Figure 22. NO_3 level in the soil according to month of growing season and crop grown. Average of four studies.

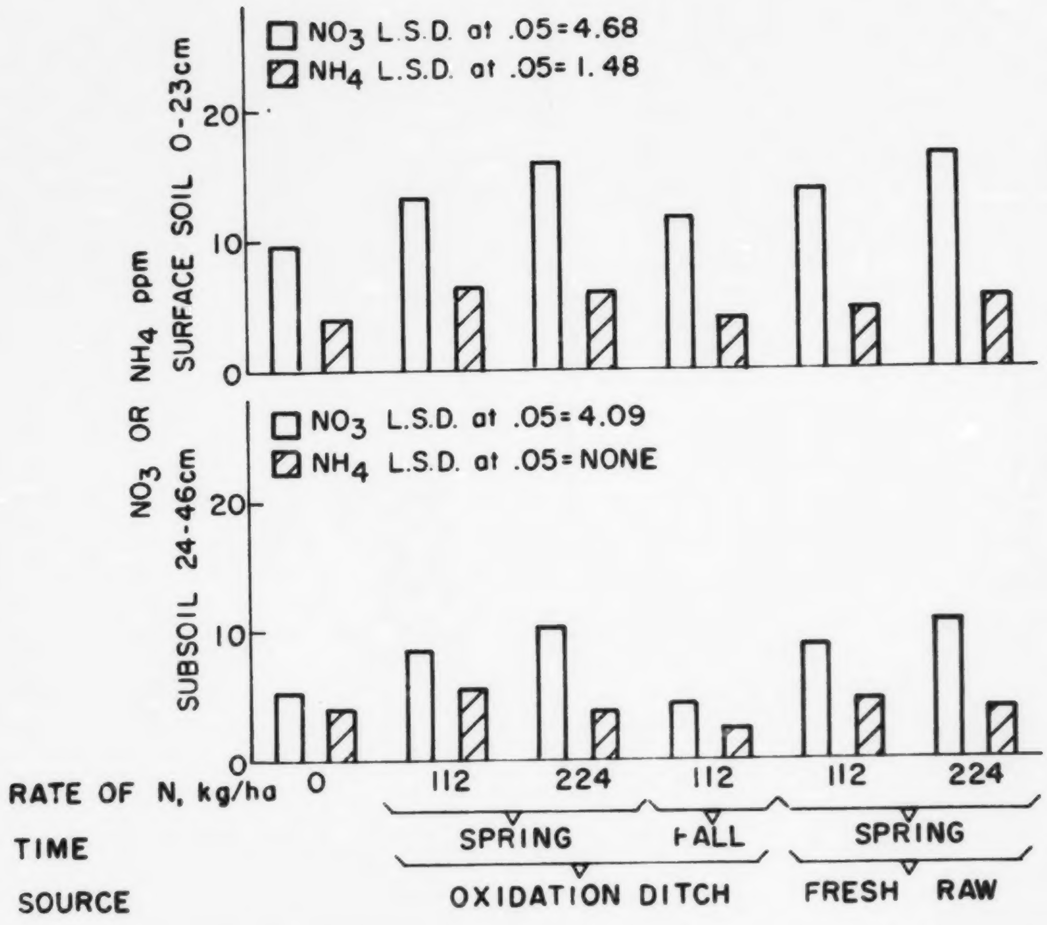

Figure 23. Average growing season NO_3 + NH_4 in the soils as influenced by the rate, form and time of poultry manure application. Poultry farm runoff study

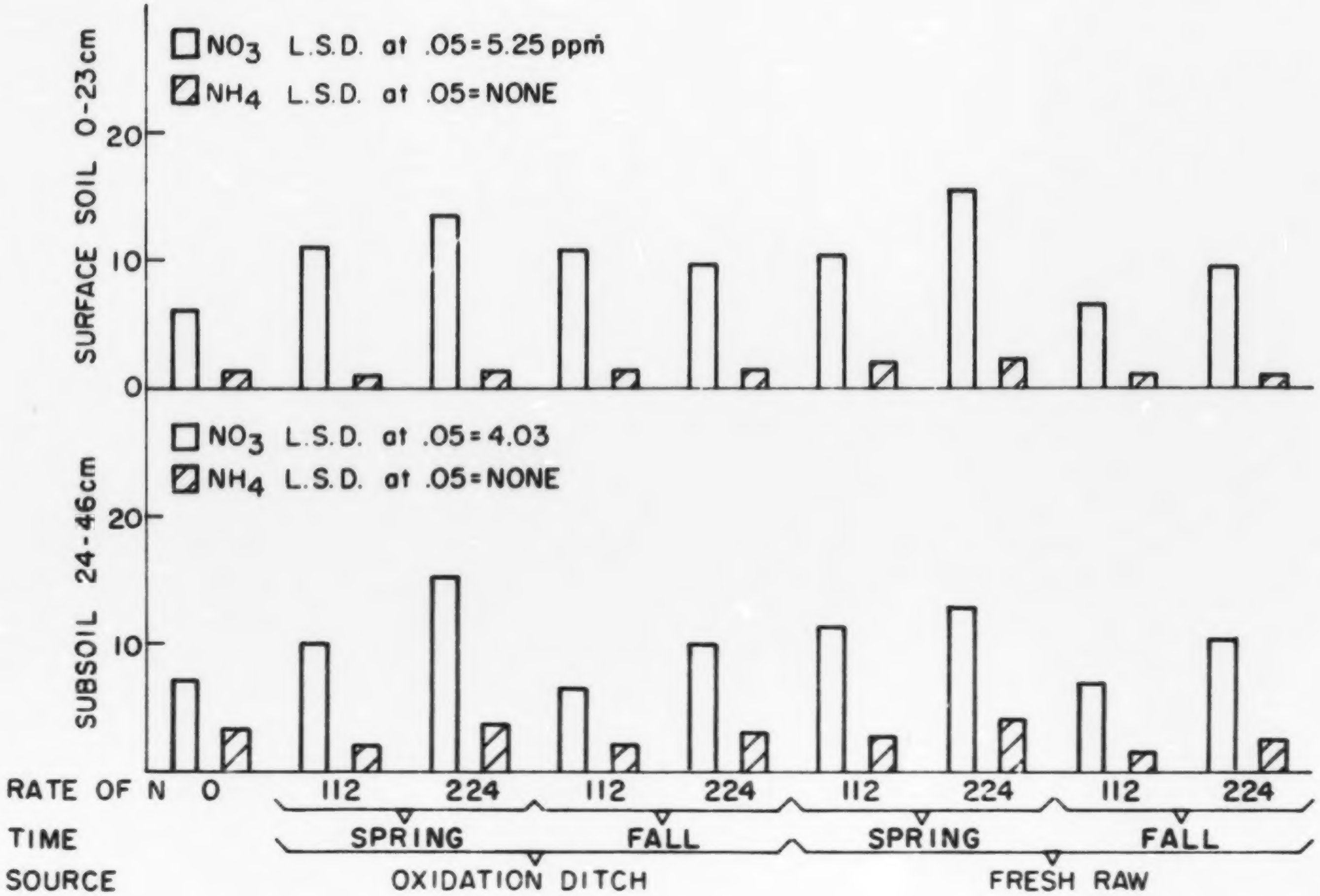

Figure 24. Average growing season $NO_3 + NH_4$ in the soil as influenced by the rate, form and time of application of poultry wastes. Aurora Farm runoff study, 1973.

have probably moved beyond the rooting depth of crop plants and have reached the groundwater. There was very little difference in the amount of nitrates found in both surface soils and subsoils as a result of source of manure (Fig. 23 and 24). Ammonium levels at the two locations and two soil depths were not greatly different from the check plots.

There were no significant volume differences in water runoff at either of the two locations except as influenced by slope. Runoff water collected during the growing season indicated no significant losses of nitrates, ammonium, total soluble phosphorus or soil sediments due to manure treatment (Tables 22 and 23).

There were significant yield increases of dry shelled grain as a result of manure applications. Application rates of manure to supply 112 and 224 kg N/ha resulted in increases above the treatment which did not receive manure. These trials suggest that either application rate of manure would produce grain yields above check treatments. Nitrogen would be released at a rate to sufficiently meet the N requirements of the corn plant but not cause excessive nitrate losses that would contaminate the groundwater. With higher manure application there was an increased uptake of N by the corn plants (Fig. 25 and 26). Although these two runoff studies were conducted on different soils at locations about 25 miles apart, the general conclusions are the same.

POULTRY MANURE RESIDUE STUDY

A study was initiated in 1971 to determine residual or carryover effects of poultry manure applied to land planted to corn. Corn was planted and harvested the year of manure application. In addition, corn was planted and harvested with one, two and three years intervals following the year of application. Measurements were made on stover and grain yields as well

Table 22. WATER, SEDIMENT AND CERTAIN NUTRIENTS LOST IN RUNOFF[a] - AURORA FARM RUNOFF STUDY, 1973-1974

	Source of Nitrogen -			Oxidation Ditch			
	Time of Application -		Check	Spring		Fall	
	Nitrogen Rate -		0	100	200	100	200
June-Oct 1973	Runoff	M³	41.3	32.3	79.9	97.2	39.7
	NH_4N	Kg/ha	0.037	0.019	0.037	0.037	0.056
	NO_3N	Kg/ha	0.190	0.176	0.669	0.646	0.370
	Ortho P	Kg/ha	0.003	0.000	0.011	0.011	0.015
	Tot. Sol. P	Kg/ha	0.011	0.011	0.022	0.011	0.011
	Soil Loss	Kg/ha	561.	327.	850.	3099.	659.
	O.M.	Kg/ha	26.86	19.11	44.74	127.60	30.14
	Total Silt Phos.	Kg/ha	0.476	0.304	0.752	2.48	0.549
	Total Silt N	Kg/ha	1.352	0.902	2.182	6.783	1.55
Nov '73-Apr '74	Runoff	M³	14.4	19.6	46.6	47.1	105.1
	NH_4N	Kg/ha	0.022	0.022	0.045	0.280	0.874
	NO_3N	Kg/ha	0.134	0.269	0.515	0.347	0.784
	Ortho P	Kg/ha	0.000	0.003	0.008	0.045	0.056
	Tot. Sol. P	Kg/ha	0.008	0.003	0.015	0.056	0.067
	Soil Loss	Kg/ha	148.6	166.9	201.6	145.6	422.2
	O.M.	Kg/ha	7.04	8.44	10.52	7.29	22.14
	Tot. Silt Phos.	Kg/ha	0.125	0.143	0.177	0.127	0.373
	Total Silt N	Kg/ha	0.403	0.414	0.514	0.362	1.082
June-Oct 1974	Runoff	M³	103.8	106.9	58.6	92.5	94.6
	NH_4N	Kg/ha	0.034	0.258	0.011	0.034	0.022
	NO_3N	Kg/ha	0.291	0.302	0.179	0.314	0.258
	Ortho P	Kg/ha	0.011	0.011	0.011	0.011	0.011
	Tot. Sol. P	Kg/ha	0.011	0.022	0.011	0.022	0.011
	Soil Loss	Kg/ha	3795.	3660.	1818.	2828.	2701.
	O.M.	Kg/ha	112.	168.	87.	110.	116.
	Tot. Silt Phos.	Kg/ha	2.70	3.05	1.44	2.21	2.20
	Tot. Silt N	Kg/ha	6.85	8.58	4.40	5.97	6.09

[a] Ave. of 3 replications

Table 22 (continued). WATER, SEDIMENT AND CERTAIN NUTRIENTS LOST IN RUNOFF[a] - AURORA FARM RUNOFF STUDY, 1973-1974

	Source of Nitrogen -			Fresh Raw			
	Time of Application -		Check	Spring		Fall	
	Nitrogen Rate -		0	100	200	100	200
June-Oct 1973	Runoff	M^3	41.3	44.2	72.1	58.8	23.6
	NH_4N	Kg/ha	0.037	0.030	0.097	0.048	0.019
	NO_3N	Kg/ha	0.190	0.213	0.549	0.433	0.109
	Ortho P	Kg/ha	0.003	0.008	0.026	0.008	0.008
	Tot. Sol. P	Kg/ha	0.011	0.011	0.034	0.011	0.011
	Soil Loss	Kg/ha	561.	428.	1432.	1699.	228.
	O.M.	Kg/ha	26.86	32.83	65.48	61.17	11.83
	Total Silt Phos.	Kg/ha	0.476	0.456	1.191	1.291	0.200
	Total Silt N	Kg/ha	1.352	1.438	3.339	3.428	0.579
Nov '73-Apr '74	Runoff	M^3	14.4	7.6	4.7	52.4	40.8
	NH_4N	Kg/ha	0.022	0.056	0.011	0.482	0.157
	NO_3N	Kg/ha	0.134	0.20	0.168	0.470	1.053
	Ortho P	Kg/ha	0.000	0.003	0.000	0.213	0.090
	Tot. Sol. P	Kg/ha	0.008	0.003	0.000	0.258	0.109
	Soil Loss	Kg/ha	148.6	56.3	78.7	257.6	41.8
	O.M.	Kg/ha	7.04	3.61	3.55	15.13	3.52
	Tot. Silt Phos.	Kg/ha	0.125	0.055	0.069	0.240	0.047
	Total Silt N	Kg/ha	0.403	0.166	0.183	0.713	0.151
June-Oct 1974	Runoff	M^3	103.8	101.8	166.5	117.2	54.5
	NH_4N	Kg/ha	0.034	0.067	0.325	0.022	0.022
	NO_3N	Kg/ha	0.291	0.336	0.672	0.347	0.302
	Ortho P	Kg/ha	0.011	0.011	0.022	0.011	0.011
	Tot. Sol. P	Kg/ha	0.011	0.022	0.022	0.011	0.022
	Soil Loss	Kg/ha	3795.	4471.	3295.	1953.	1790.
	O.M.	Kg/ha	112.	108.	150.	84.	64.
	Tot. Silt Phos.	Kg/ha	2.70	3.00	2.74	1.59	1.36
	Tot. Silt N	Kg/ha	6.85	7.27	7.71	4.40	3.57

[a] Ave. of 3 replications

Table 23. WATER, SEDIMENT AND CERTAIN NUTRIENTS LOST IN RUNOFF - POULTRY FARM RUNOFF STUDY, 1972-1973[a]

	Nitrogen Source - Time of Application - Nitrogen Rate -		Check	Oxidation Ditch			Fresh Raw	
				Spring		Fall	Spring	
			0	100	200	100	100	200
June - Oct. 1972	Runoff	M^3[b]	53.5	53.5	28.8	--	93.5	43.2
	NH_4N	Kg/ha	.045	.056	.034	--	.134	.045
	NO_3N	Kg/ha	1.90	2.93	.627	--	3.18	.77
	Ortho P	Kg/ha	.011	.034	.011	--	.011	.011
	Total Sol. P	Kg/ha	.034	.034	.011	--	.034	.011
	Soil Loss	Kg/ha	1327.	3615.	1363.	--	1267.	486.
	Organic Matter	Kg/ha	27.58	99.15	36.01	--	47.07	18.20
	Total Silt Phos.	Kg/ha	.93	2.52	.94	--	.97	.37
	Total Silt N	Kg/ha	1.08	6.27	.011	--	.045	.011
June - Oct. 1973	Runoff	M^3	19.7	36.4	8.4	17.4	43.7	37.5
	NH_4N	Kg/ha	.054	.050	.188	.025	.097	.129
	NO_3N	Kg/ha	.292	.430	.174	.144	.550	.480
	Ortho P	Kg/ha	.009	.017	.009	.009	.011	.015
	Total Sol. P	Kg/ha	.011	.022	.034	.022	.022	.022
	Soil Loss	Kg/ha	190.	806.	10.	235.	1107.	380.
	Organic Matter	Kg/ha	6.	31.61	.57	7.11	37.59	12.06
	Total Silt Phos.	Kg/ha	.13	.64	.01	.17	.83	.28
	Total Silt N	Kg/ha	.36	1.71	.03	.43	2.16	.72

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[a] Average of 4 replications

[b] Six selected storms

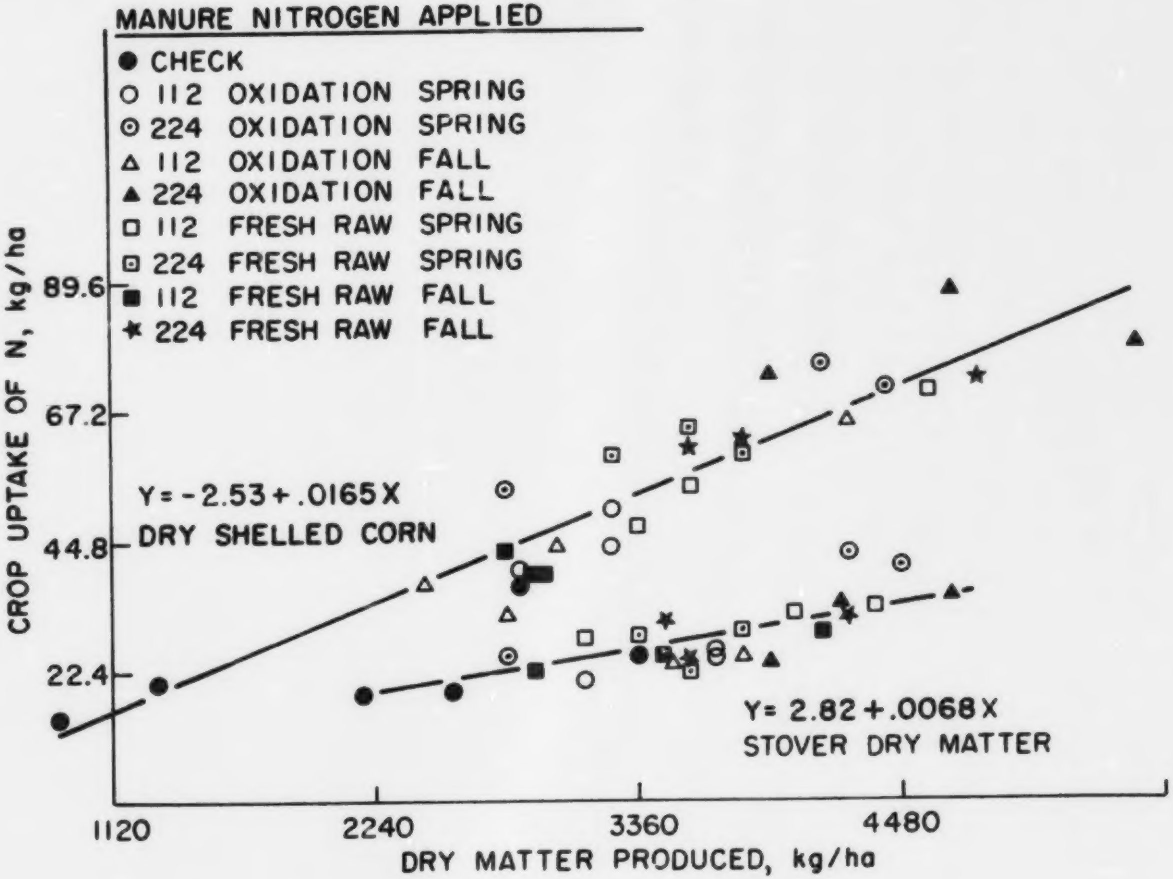

Figure 25. Relationship of nitrogen uptake in grain and stover to dry matter produced. Aurora Farm runoff study, 1973.

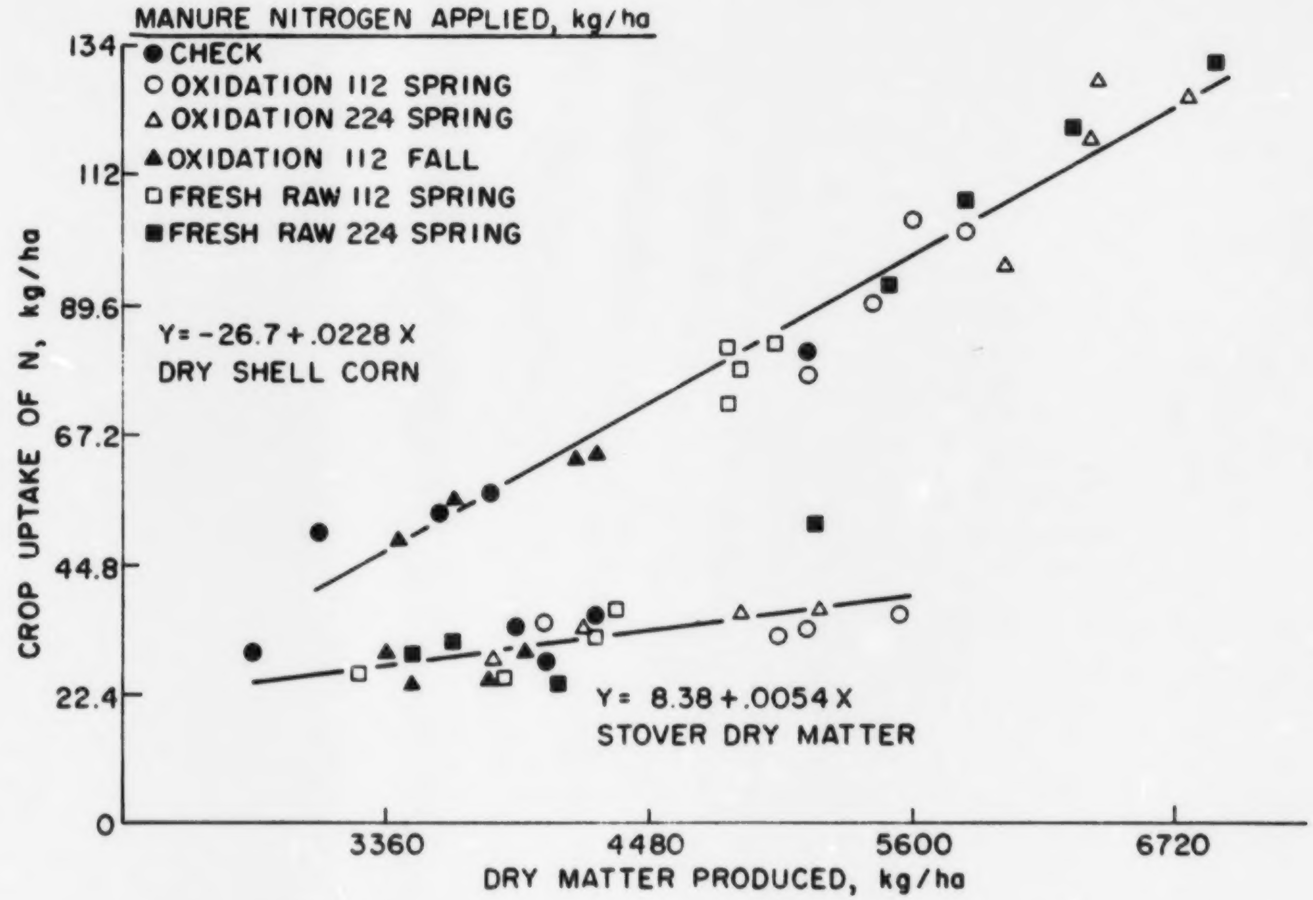

Figure 26. Relationship of nitrogen uptake in grain and stover to dry matter produced. Aurora Farm runoff study, 1973.

as the N content of the stover and grain. Soil samples at 0-23 cm and 25-45 cm depth were taken and nitrate content determined.

The average nitrate content of soils for the 1973 growing season according to treatment is presented in Figure 27. Nitrate levels under manure treated plots were higher in the surface soil than the subsoil for a given treatment. The highest nitrate level in the subsoil occurred when commercial fertilizer N had been applied. Subsoil nitrate levels under manure treated plots were not significantly different from the check or no manure treatment. This indicates that very little nitrate from manure at the 112 and 448 kg N/ha treatment moved into the subsoil.

Corn grain yields for the 1972 and 1973 growing season have been averaged according to four of the treatments (Fig. 28). The 1974 grain yields are presented in Figure 29. In 1974, the only treatment receiving nitrogen was the commercial fertilizer treatment. All others were residuals of various manure treatments with intervals of one, two, or three years since manure application. From these data on corn yields according to rate and year of application, one can draw inferences regarding the release of N from poultry manure. About 50 percent of the N in poultry manure, either oxidation ditch or fresh manure, is available the first year. Of the remaining N in the manure, only very small amounts are mineralized in succeeding years and available for plant use (Fig. 29).

As was the case with the runoff studies, there was a good relationship between corn dry matter produced and crop uptake of N (Fig. 30). Earlier results and conclusions from this study have already been published (5).

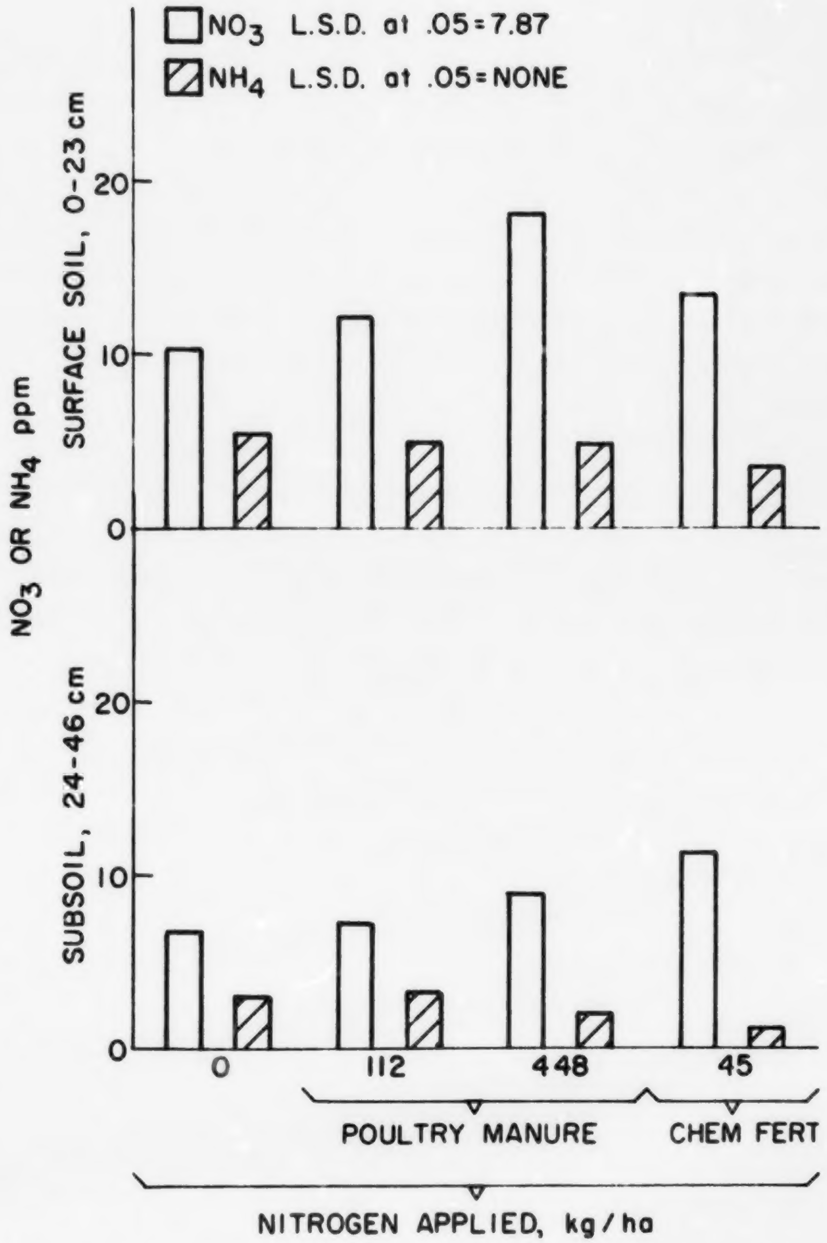

Figure 27. Average NO_3+ NH_4 in the soil during 1973 growing season as influenced by rate of ODML and commercial fertilizer. Aurora Farm residue study, 1973.

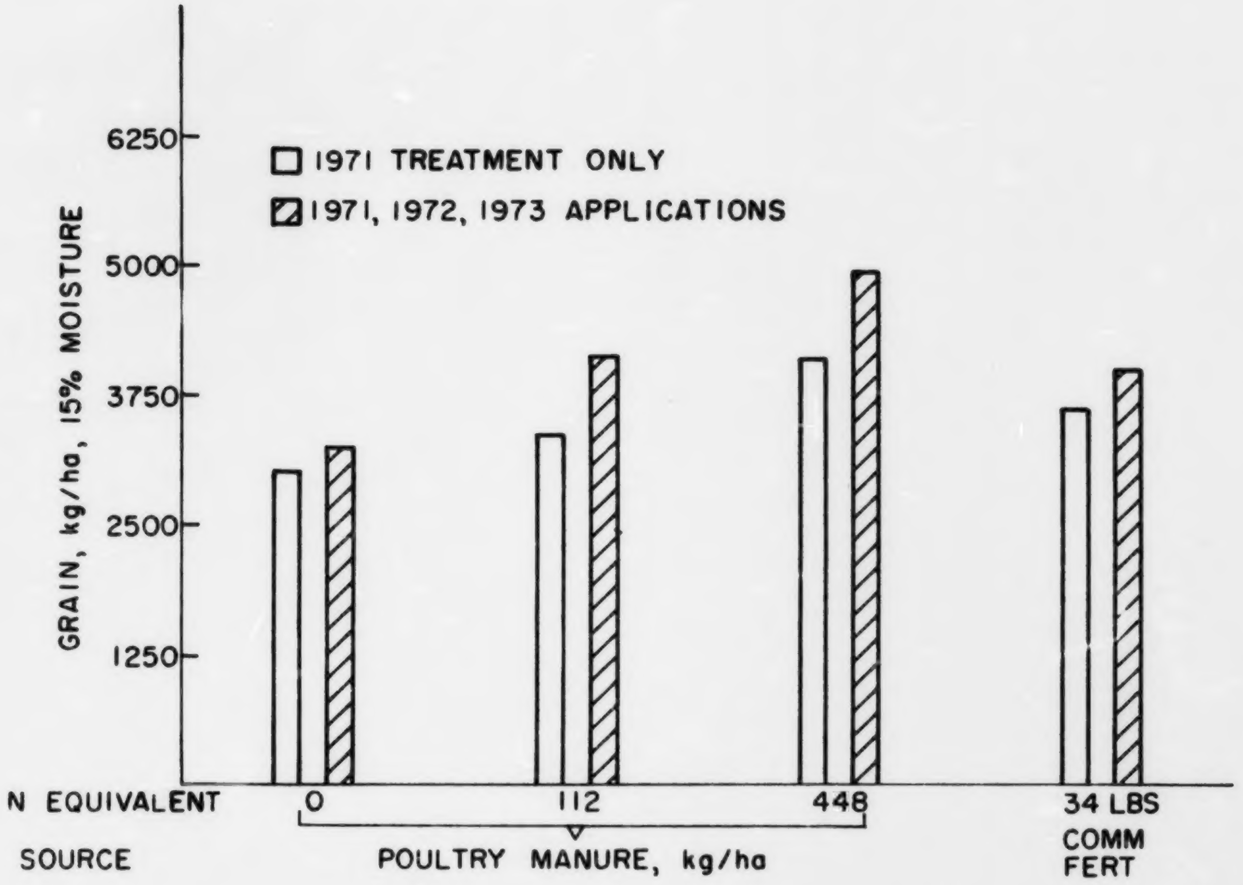

Figure 28. Two year average yield (1972 and 1973) on poultry waste residue study. Aurora, New York.

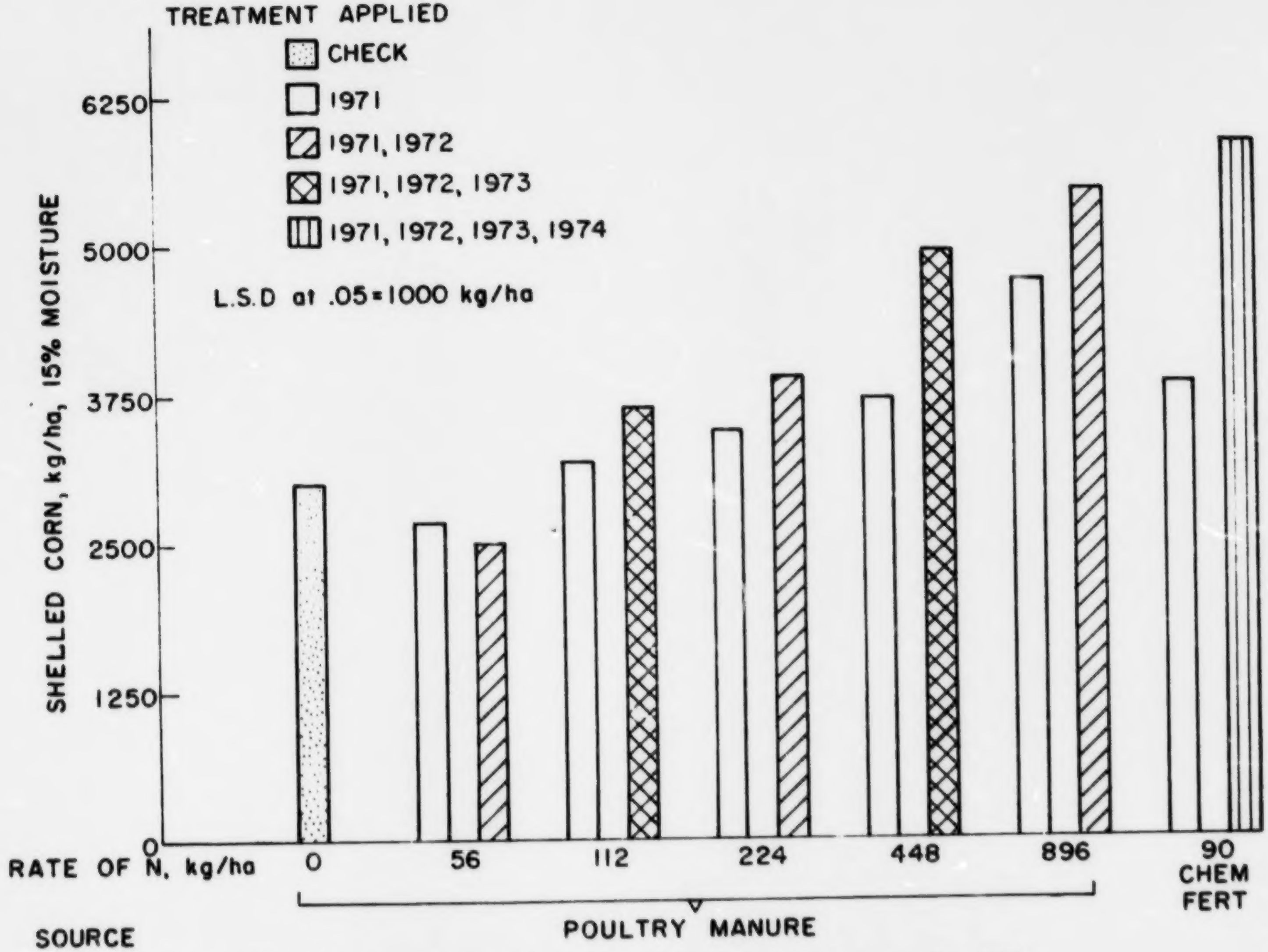

Figure 29. 1974 yields from poultry waste residue study. Aurora, New York.

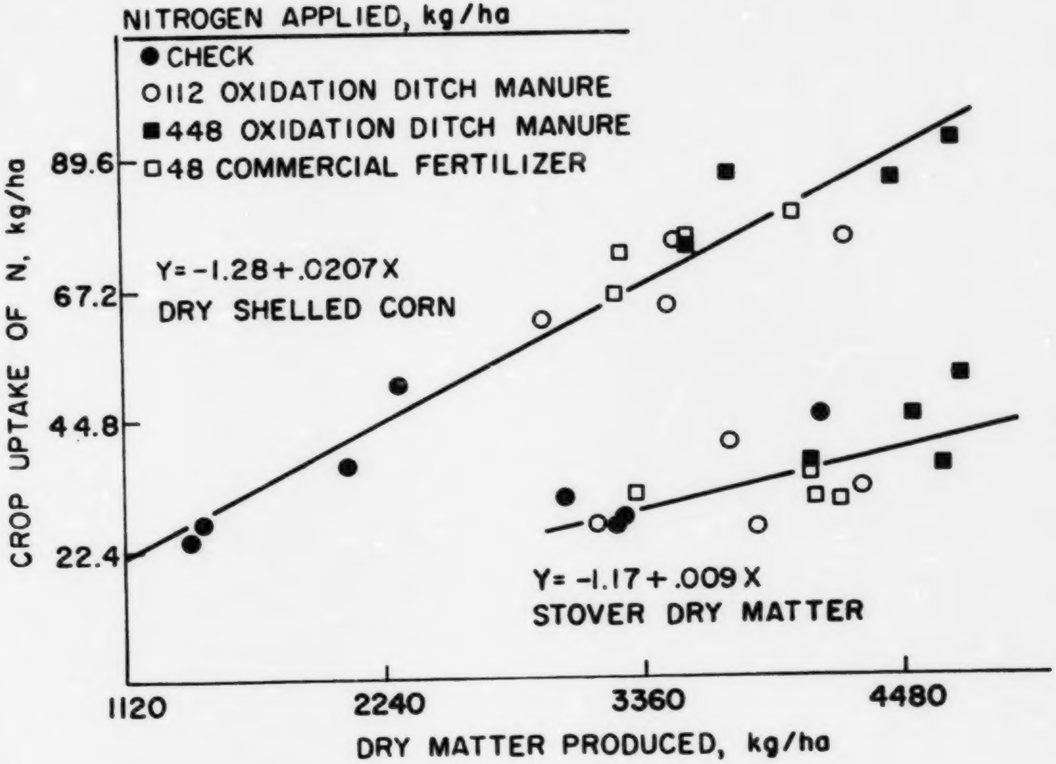

Figure 30. Relationship of nitrogen uptake in grain and stover to dry matter produced. Poultry waste residue study. Aurora, New York, 1973.

GRASS RESPONSE TO APPLICATIONS OF POULTRY MANURE

Poultry manure and chemical fertilizers were used as a source of N on orchard grass and bromegrass. This study was an attempt to evaluate the timing and rate of application of poultry manure as an effective source of N. Oxidation ditch manure, fresh manure without litter and commercial fertilizer N were applied the first weeks of November 1972 and May 1973. The two manure sources were applied at rates of 0, 56, 112, and 224 kg N/ha. Commercial fertilizer was applied at the rate of 56 kg N/ha.

Yields of orchard grass according to treatment are presented in Figure 31. Orchard grass responded well to all manure treatments applied in both spring and fall. This grass did not respond well to commercial fertilizer N.

Bromegrass (Fig. 32) responded best to the 224 kg N/ha rate at each time of application and each source except for the spring applied fresh poultry manure. These grass yield responses to various rates and time of application indicate that perennial forages such as orchard grass and bromegrass can utilize N supplied by either oxidation ditch or fresh poultry manure. Either fall or spring applications would not only benefit the forage but provide flexibility in terms of time to dispose of the manure. It can be generalized that grass response favored fall applications.

The relationship between N uptake and dry matter produced for orchard grass and bromegrass is presented in Figures 33 and 34 respectively.

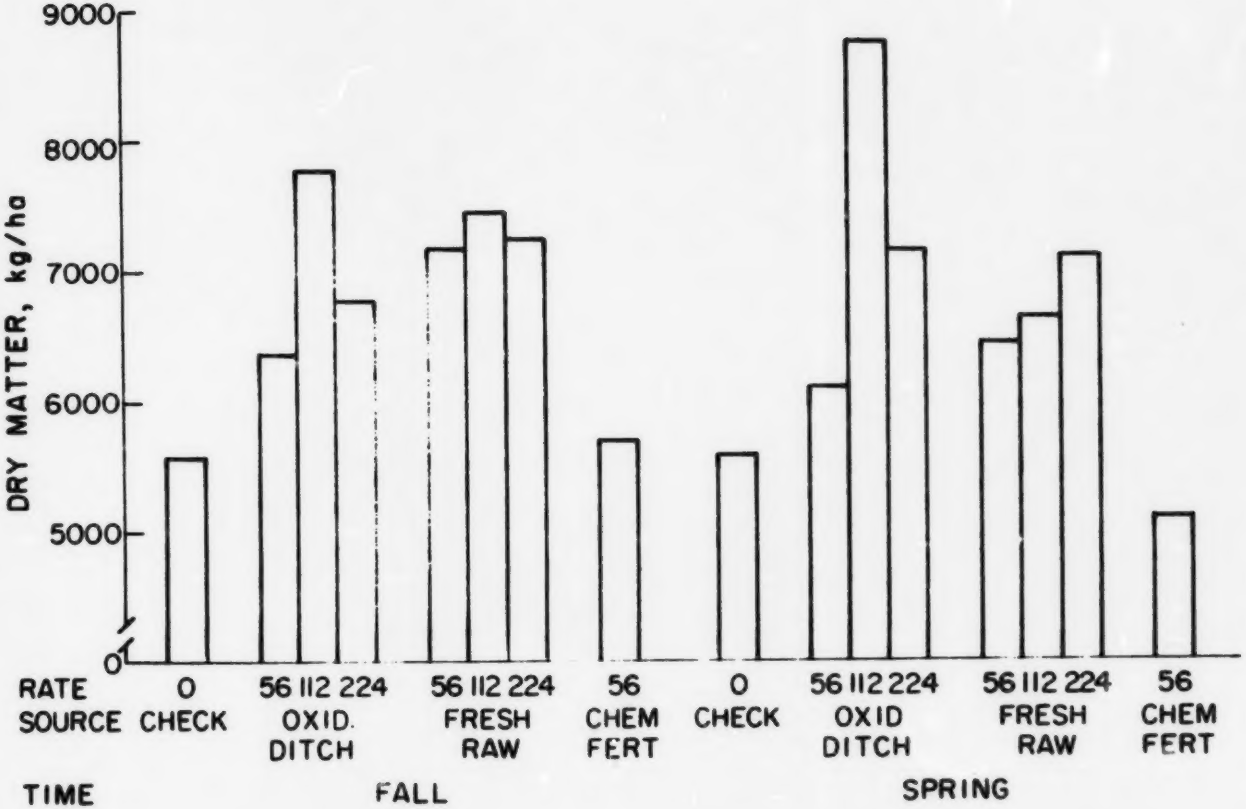

Figure 31. The effect of source, rate and time of application of poultry manure and commercial fertilizer on the yield of orchard grass (2 cuttings) L.S.D.@ .05 = 1255. Aurora Farm grass study, 1973.

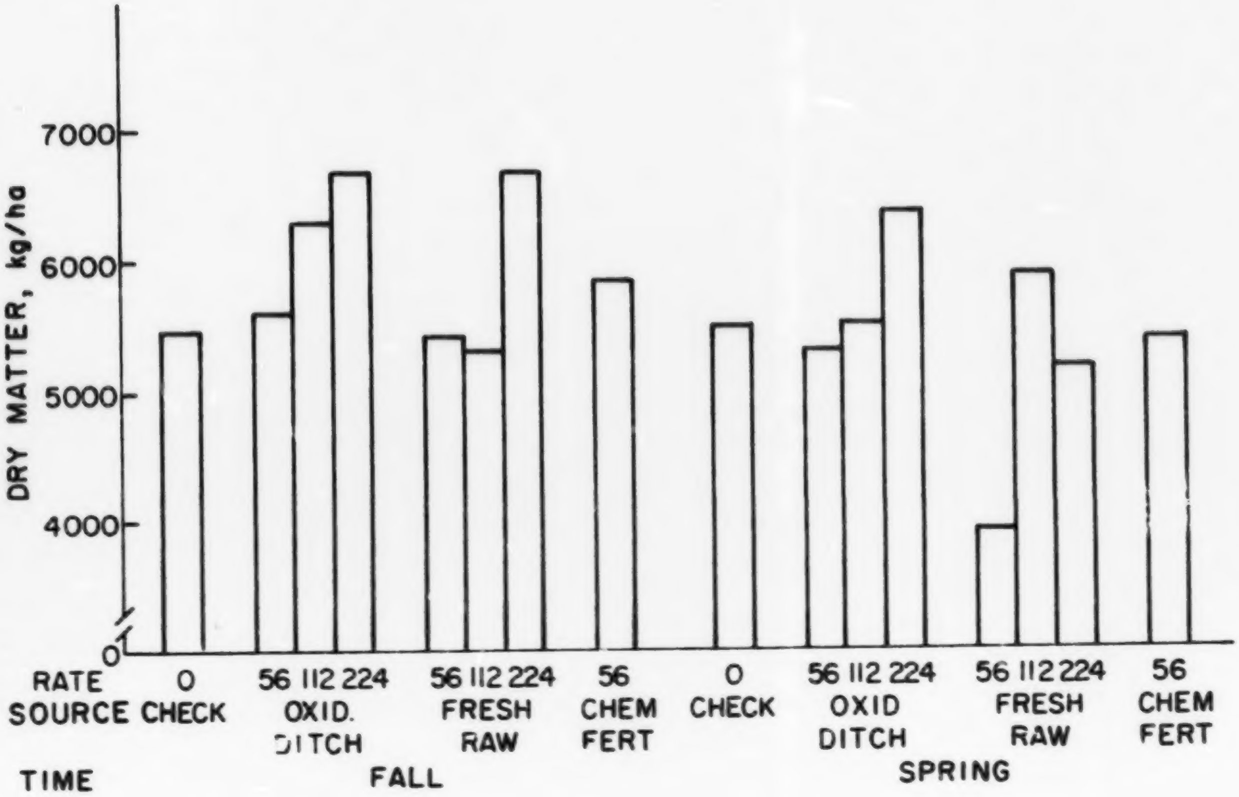

Figure 32. The effect of source, rate and time of application of poultry manure and commercial fertilizer on the yield of orchard grass (2 cuttings) L.S.D.@ .05 = 1939. Aurora Farm grass study, 1973.

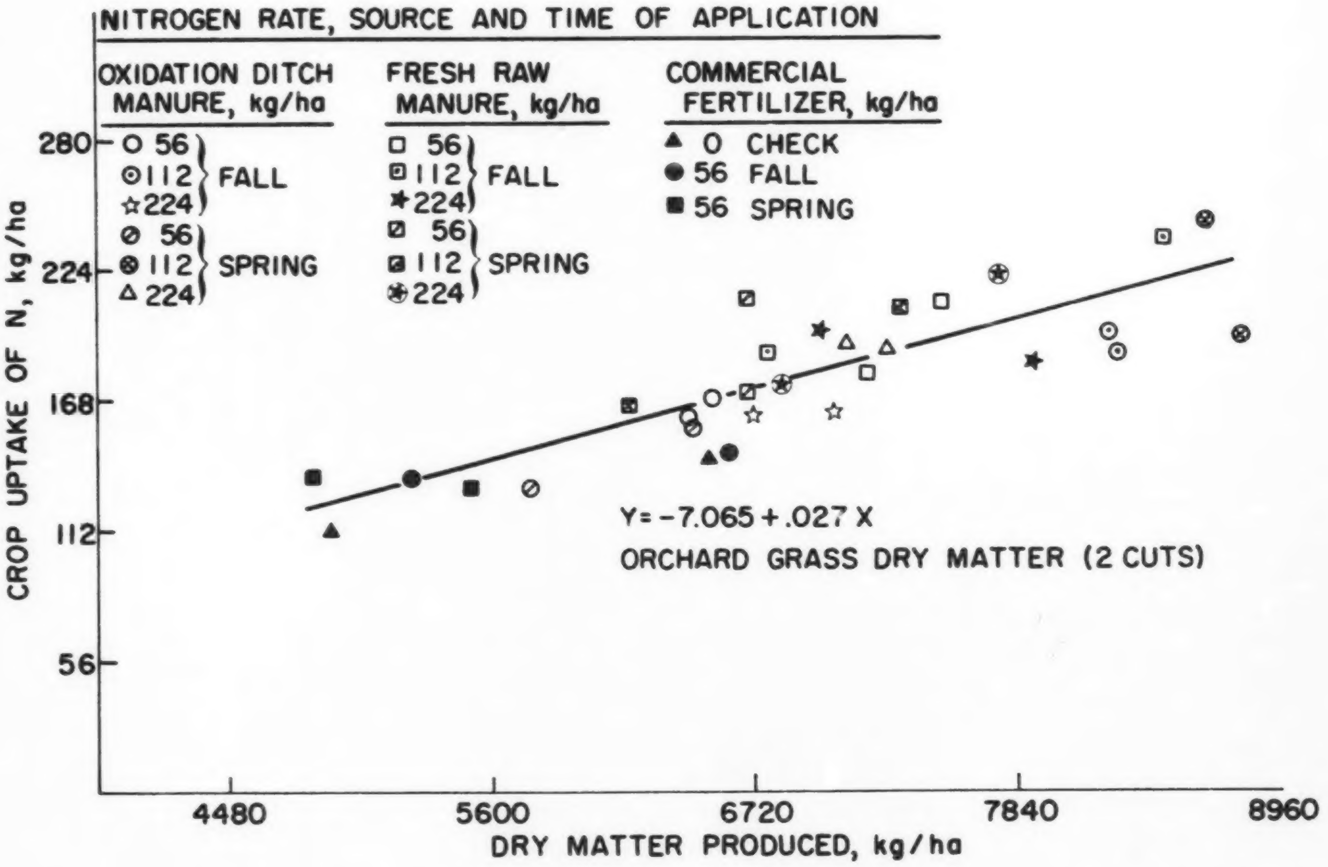

Figure 33. Relationship of nitrogen uptake in orchard grass to dry matter produced. Aurora Farm grass study, 1973.

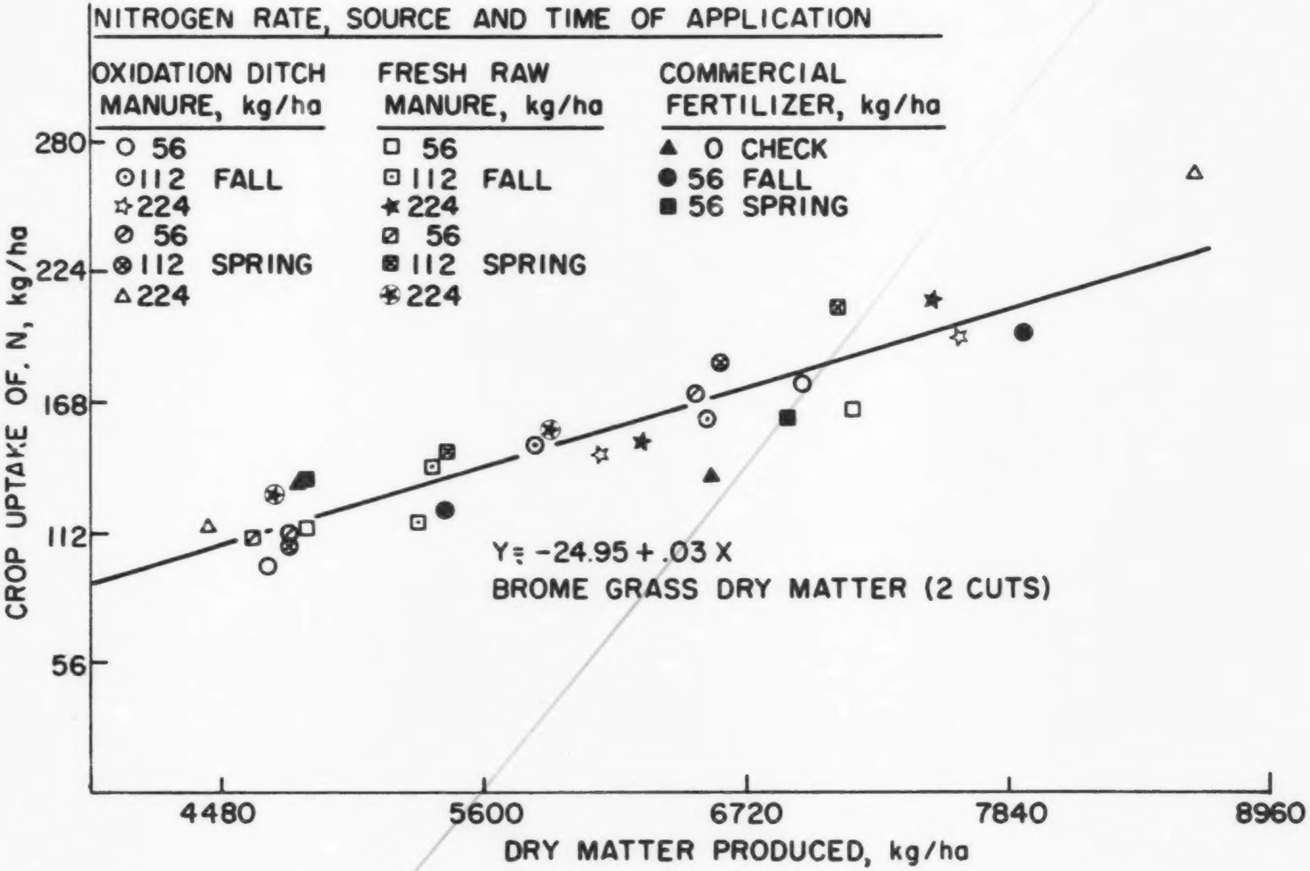

Figure 34. Relationship of nitrogen uptake in bromegrass to dry matter produced. Aurora Farm grass study, 1973.

SECTION VI

DISCUSSION OF EXPERIMENTAL RESULTS

GENERAL

Unless livestock wastes are properly stabilized and managed, they may pose environmental problems. Because land is the ultimate disposal medium for livestock wastes, there is no need to process the wastes to obtain degrees of stabilization comparable to those of effluents discharged to surface waters. Livestock waste treatment objectives will be based on other factors. Land application rates can be a controlling factor whether land is used for crop cultivation or for disposal.

Uncontrolled nitrogen losses have been reported in animal waste stabilization systems (20-27). The results of our investigations on aerobic stabilization of animal wastes confirm these observations. Investigations of this project also indicated that it is possible to control the losses of nitrogen by manipulating the operation of the oxidation ditch.

Based on the project evidence collected in the laboratory and pilot plant studies on the effect of some factors influencing the stabilization of animal wastes, some design criteria have been developed. These criteria have permitted the design and operation of a waste stabilization system for a mink farm and have assessed the performance of two full scale stabilization systems in operation at the poultry farms. The continued observation on the full scale systems also have permitted better identification of inherent managerial problems associated with the operation of stabilization systems.

These studies have also been useful in the development of management models for animal waste stabilization including nitrogen control (28). It is now possible to alter the nitrogen removal efficiency of the stabilization system without impairing the efficiencies of removal of total solids and COD. Differences in nitrogen losses from the stabilization systems can be achieved by varying oxygen inputs to the system without significantly altering the nitrifying activity in the system.

The observed nitrogen losses were found to be the lowest when the system was kept aerobic at all times; however, these losses can be increased by any of three approaches: (a) denitrify the mixed liquor in a separate solids separation unit without stopping the aeration in the oxidation ditch, (b) denitrify the mixed liquor _in situ_ by stopping the aeration for an optimal time, which is related to the condition at which the oxidation ditch was operating, and (c) manipulate the design of the rotor such that there is an adequate dissolved oxygen concentration for some distance from the rotor to accomplish nitrification and it is absent in the remainder of the ditch to achieve denitrification.

NITROGEN CONSERVATION

It is difficult to operate a waste treatment system without losing some nitrogen. Anoxic pockets and the microaerophilic and facultative conditions prevailing at the floccular level of the mixed liquor enhance denitrification and generally precluded the possibility of conserving all the nitrogen entering the system. In addition, some ammonia volatilization could occur before nitrification occurs. Even if a significant concentration of dissolved oxygen is maintained in the mixed liquor, some loss of nitrogen will occur. If conservation of nitrogen is the objective, such losses should be minimized by operating the ditch appropriately.

The results of the first two modes of operation discussed in this paper indicate the opportunities that exist for controlling nitrogen losses. Liquid aeration systems operated either as continuously filled reactors without wasting of mixed liquor (mixed aerobic holding tanks), or as continuous flow devices exhibited only a 30% loss of the input nitrogen. Aerobic holding tanks for poultry wastes should be kept below a total solids concentration of 2% since oxygen transfer becomes less efficient beyond that concentration (18). In the continuous flow operation, solids concentration can be controlled at an optimal level for maximum oxygen transfer. Nevertheless, even at a total solids concentration of ≈5000 mg/l at which O_2 transfer efficiency was not impaired in the mixed liquor and D.O. concentrations were generally above 5 mg/l, about 30% of the total nitrogen input was lost. Thus in oxidation ditches operating under highly aerobic conditions, it may be difficult to conserve more than 70% of the nitrogen fed into the system. However, it may be possible to conserve more nitrogen than was possible in the current study by: (a) minimizing the probability of occurrence of anoxic conditions in the mixed liquor suspended solids by efficient mixing and maintaining a high D.O. concentration in the ditch, and (b) operating the ditch at a low mixed liquor total solids concentration (0.5 - 1.0%) and incorporating frequent removal of the mixed liquor.

PARTIAL NITROGEN CONSERVATION

Assuming that crop growth is integrated with the disposal of oxidation ditch effluent on land, it may be desirable to remove only a fraction of the nitrogen present in the mixed liquor if the land available for disposal is limited. In such situations only partial conservation of nitrogen may be sufficient to meet the suggested or required nitrogen application rates. From the results obtained in this study, this objective can be accomplished by programming in situ denitrification schedules, while allowing the ditch to operate as a continuous flow device. For example, in Operational Mode II, the 62.1% of the total nitrogen that passed through the oxidation ditch with the effluent (Table 14) could have been made less, if the duration of the continuous flow-through periods was curtailed and periods of denitrification followed by nitrification of a shorter duration repetitively followed one another. However, such denitrification periods can only be introduced after a continuous flow-through period when NO_3-N is present in the mixed liquor, since without NO_3-N in the mixed liquor,denitrification can not take place. Thus careful manipulation and monitoring of the nitrification phase of the oxidation ditch operation and judicious introduction of a denitrification phase after each of the nitrification phases is needed to achieve the desired nitrogen removal. The amount of nitrogen removal depends on the number of nitrification-denitrification phases during a given period of the oxidation ditch operation.

Partial removal of nitrogen from ODML can also be accomplished by practicing intermittent rotor aeration. Varied degrees of nitrogen removal can be accomplished by manipulating the period of rotor aeration. Thus for example, higher nitrogen removal was obtained in an operation having 12 hr rotor-aeration/day than in 13 to 24 hr rotor-aeration/day.

MAXIMUM NITROGEN REMOVAL

The results of this study indicated that a very high percentage of nitrogen removal, up to 90%, of input nitrogen, can be accomplished. This can be achieved by including a denitrification-settling tank and recycling of the supernatant to the oxidation ditch or by manipulating the aeration of the mixed liquor. An advantage with recycling the supernatant is the conservation of water.

Previous studies (21) showed that nitrifying organisms can withstand prolonged anaerobiosis, and can easily nitrify poultry waste mixed liquor when once aerobiosis is restored. Taking advantage of this observation, an operational mode for the oxidation ditch was studied. In this mode (Mode IV), the mixed liquor was aerated only partially in a day to achieve nitrification. It was then subjected to anaerobiosis during the remaining portion of the day to achieve the denitrification of the oxidized nitrogen formed during the aerobic phase. This mode of operation also provided an opportunity for removing the end products of ammonia oxidation, thereby relieving any inhibition of nitrification due to enzyme repression by these end products. By resuming aeration of the mixed liquor after the anaerobic period, nitrification once more occurred and the oxidized nitrogen was removed in another anaerobic phase. Thus by manipulating the denitrification phases, it is possible to accomplish variable losses of nitrogen as well as maximum nitrogen control.

The effect of varying periods of aeration on the nitrogen losses from the oxidation ditch are shown in Figure 35. These results suggest that it is possible to achieve varying degrees of nitrogen removal in the range of 30 to 90 percent, by suitably adjusting the period of aeration and in situ denitrification in the oxidation ditch. In view of the results of the current study, the following nitrogen losses can be expected depending on the mode of operation of the oxidation ditch (Table 24).

Other modes of operation are possible by using combinations of the above modes. It should be possible to achieve different degrees of nitrogen removal with different combinations of the above modes of operation by controlling the effective denitrification time without seriously affecting the performance of the nitrification phase.

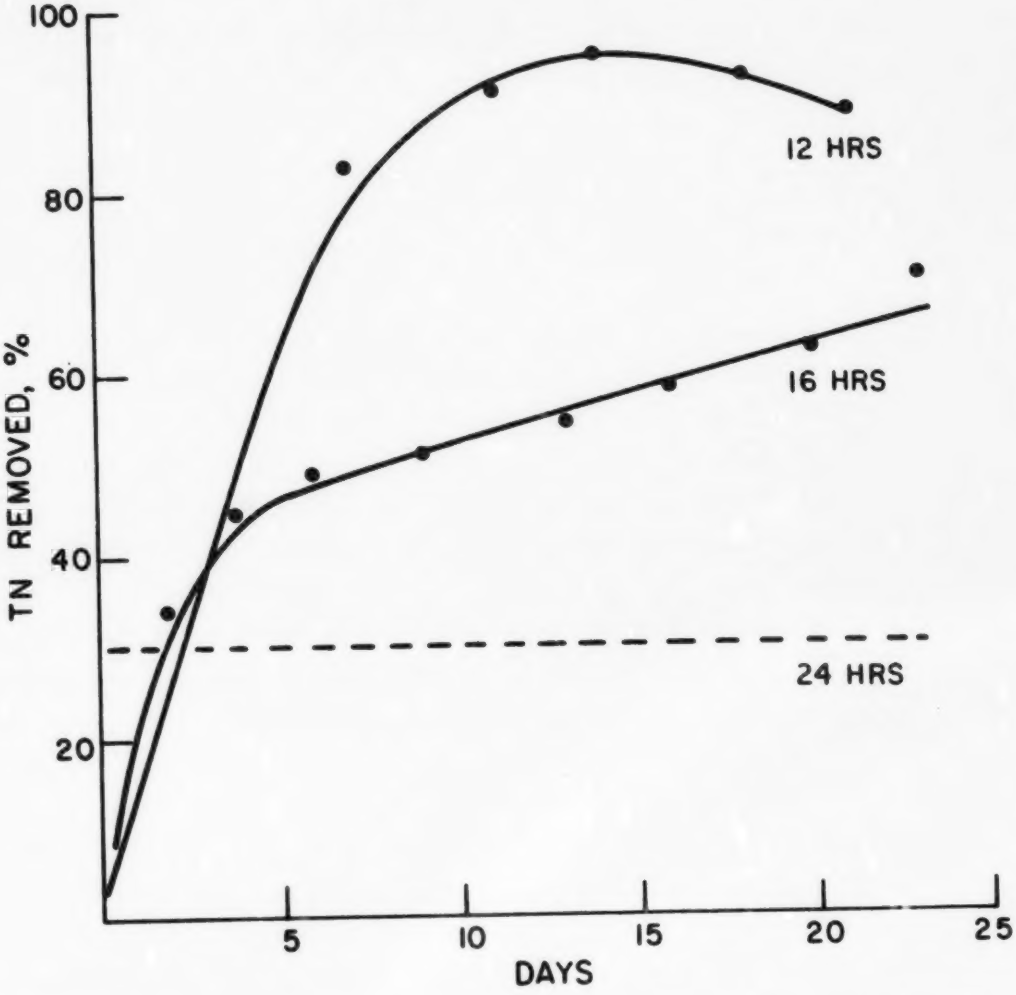

Figure 35. Aeration period and nitrogen losses in an oxidation ditch.

Table 24. SUMMARY OF EXPECTED NITROGEN LOSSES IN DIFFERENT MODES OF OXIDATION DITCH OPERATION

Mode of operation	Expected % of TN loss
1. Continuously filling device	≈30
2. Continuous flow operation with *in situ* denitrification	≥30 depending on the number of *in situ* denitrification time phases
3. Continuous flow operation and recycling of supernatant via a settling-denitrification tank	≈75
4. Semi-continuous or continuous operation with partial rotor aeration, (12 to 16 hrs/day only)	≈90 less % of removals can be achieved by prolonging the aerobic phase and curtailing the denitrification phases

COD REMOVAL IN NITROGEN CONTROLLING SYSTEMS

Approaches that have achieved the nitrogen control objectives can not justifiably be applied to agricultural waste treatment systems unless other environmental objectives such as odor control and some degree of waste stabilization also are realized. The results of this study indicated that odor control was achieved in all the modes of operation. Odor was not perceived even when the nitrified mixed liquor was subjected to anoxic conditions for about two to three weeks.

Chemical oxygen demand balances were computed for all modes of the oxidation ditch operation and summarized in Table 25.

Table 25. COD LOSSES IN AN OXIDATION DITCH DURING VARIOUS MODES OF OPERATION

	Mode of operation	% COD loss	
I.	Continuously filling mode with continuous rotor aeration	62.5	
II.	Continuous flow mode with *in situ* denitrification		
	a) filling periods	4.9	50.9
	b) flow-through periods	34.5	
	c) *in situ* denitrification periods	11.5	
	d) COD loss via effluent	49.0	
III.	Continuous flow mode with recycling of supernatant from a settling tank	53.0	
IV.	Continuous filling mode with curtailed rotor aeration		
	a) 12 hrs/day	59.0	
	b) 16 hrs/day	51.4	

COD removals of 50-60% were achieved irrespective of the mode of operation of the ditch used to control nitrogen. Although high COD removals are not required for the disposal of treated wastes on land, approaches presented in this study for the control of nitrogen do provide other benefits such as accomplishing odor control and waste stabilization.

MANAGEMENT MODEL FOR WASTE STABILIZATION

Conventional agricultural practices have placed little emphasis on the management of animal wastes. With the increasing public concern towards preservation of environmental quality and the recently imposed restrictions on disposal of animal wastes, proper management of manures has assumed greater importance. There is no one type of waste stabilization and management system that will be satisfactory for every type of production facility.

Management objective is a major factor in the choice of the system. The choice of a stabilization system should be viewed as the last step in the choice of alternatives for handling animal wastes. If possible, the animal production facility should be located away from the suburbia or land areas having minimal resources for safe disposal of manure. By proper choice of housing for animals, and scheduling of waste removal, it may be possible to mitigate the pollutional problems. If this initial care in planning the production facility is not adequate to prevent environmental problems, then a stabilization system may become a necessary addition to the waste management system.

The objectives of stabilization will be determined by the nature of constraints. If the production facility is located near suburban housing, odor control is an important objective of waste management. If this facility is away from the suburbia, there may be no need to control odors, and the manure may be disposed of by spreading on land. If sufficient land is available to grow grains for feeding animals, it would be logical to use the manure to fertilize the land since fertilizers are in short supply. If the facility is near a housing area and adequate crop land also is available, the objectives of stabilization would be (a) control odor, and (b) maximum conservation of nitrogen. If on the other hand, adequate land is not available to spread the manure, removal of the excess nitrogen instead of nitrogen conservation, would be the nitrogen control objective.

In view of the observations on the performance of oxidation ditches, it would appear that waste stabilization in an oxidation ditch would perhaps be the most feasible means of achieving the objectives. The performance of the oxidation ditch is largely dependent on the oxygen inputs to the system. Using the available data, a mathematical model has been developed (29) to describe the oxygen requirements for (a) odor control; (b) nitrogen removal; and (c) maximum nitrogen conservation.

In an aerobic biological treatment system, a reasonably accurate estimate of the amount of oxygen-demanding material is necessary in order to properly size the aeration equipment. There are two important groups of oxygen-demanding material in poultry waste. First, oxygen is needed to oxidize the organic carbon which is present in the waste material. This carbonaceous oxygen demand can be estimated by the chemical oxygen demand (COD) if nitrite ions are not present in the wastes. In addition to this carbonaceous demand, oxygen also may be needed to oxidize the ammoniacal nitrogen resulting from the hydrolysis of nitrogenous organic matter.

Raw poultry waste contains nitrogen mainly in the form of polypeptides, amino acids and uric acid. Ammonification is carried out by a diverse group of microorganisms. It is a process whereby the organic nitrogen compounds are metabolized to ammonia primarily by the deamination of the amino acid residues and the hydrolysis of uric acid. If sufficient oxygen is present in the system, autotrophic nitrifying bacteria will develop and oxidize NH_4^+ to nitrite and nitrate. For every gram of ammonium nitrogen oxidized to NO_3^-, 4.57 g of oxygen are required.

The total amount of oxygen which must be supplied to the mixed liquor will depend upon the objectives of stabilization. If the system is to be operated only to control odor, then the rotor may be designed to supply only sufficient oxygen to meet the carbonaceous demand. On the other hand, if the system is used to minimize nitrogen losses, enough oxygen must be supplied to meet both the carbonaceous and the nitrogenous demands. This same quantity of oxygen may also be required for maximum nitrogen removal since good nitrification is a prerequisite to subsequent denitrification.

In a completely aerobic biological system, oxygen is used as the terminal electron acceptor. Under anaerobic conditions, organic carbon, carbon dioxide, nitrate ions, and sulphate ions will be used as terminal electron acceptors. The production of reduced organic compounds such as ammonia, sulfides, mercaptans, amines, organic acids and methane will result. Certain of these compounds are responsible for the undesirable odors released under anoxic conditions. The amount of oxygen which must be supplied to prevent anaerobiosis is assumed to be that quantity required to meet the demand of the oxidizable COD. Not all of the biodegradable COD will utilize oxygen since some of it will be incorporated into cell mass. At the ideal steady state conditions which have been assumed in this model, organic matter will not accumulate in the system. Therefore the amount which is oxidized at steady state conditions is equal to the difference between the amount added in the raw waste and the amount present in the mixed liquor. This can be expressed by the following equation:

$$f_c \cdot 0_i = 0_i - 0_o \tag{15}$$

where f_c = fraction of the influent organic matter which is oxidized
0_i = rate of addition of organic matter (mass/time)
0_o = rate of removal of organic matter (mass/time).

The oxidation of organic carbon can be expressed directly as an oxygen demand. Each unit by weight of COD which is oxidized requires one unit weight of oxygen. The following equation, derived from the mass balance approach above, was used in this study to determine the rate at which oxygen must be supplied to the mixed liquor for odor control:

$$R = f_c \cdot S \cdot n \tag{16}$$

where R = microbial oxygen demand, (mass/time);
S = rate of COD loading to the ditch, (mass/bird-time)
n = number of birds.

Oxygen Demand for Nitrogen Control

In an aerobic biological treatment system, nitrogen may be removed by ammonia desorption or by nitrification followed by denitrification. The latter is the more effective and controllable method for the removal of nitrogen in livestock wastes. The most efficient means of storing nitrogen in a biological system is to oxidize the ammoniacal nitrogen to nitrate ions and to avoid subsequent denitrification. Consequently, if the treatment objective is either to remove nitrogen or to conserve nitrogen, enough oxygen must be supplied to meet both the carbonaceous as well as the nitrogenous demand. The amount of nitrogen which will exert an oxygen demand is assumed to be the biodegradable fraction of TKN. A small quantity of this fraction will be incorporated into cell growth. Since only a relatively small portion of the large supply of ammoniacal nitrogen available in animal wastes will be used in cell synthesis; however, the assumption is valid for the purposes of this study.

The total oxygen demand is the sum of carbonaceous and nitrogenous demands and is expressed in the model by the following equation:

$$R = n\ (f_cS + 4.57\ f_NS_N) \qquad (17)$$

where f_N = fraction of TKN which is biodegradable
S_N = rate of TKN loading to the ditch, (mass/bird-time).

Power and Oxygen Requirements

The quantity of power required to achieve adequate aeration is a function of the amount of oxygen demanding material added to the ditch and of the management objectives. Since the efficiency of oxygen transfer decreases as the total solids concentration increases, power requirements for the same oxygen input will increase with increases in the solids concentration of the mixed liquor. More oxygen is needed for nitrogen removal and nitrogen conservation than for mere odor control. It is useful for the designer and operator of the waste management system to know what the economic trade-offs will be between these objectives.

The power requirements for achieving odor and nitrogen control objectives, at different solids concentration in the ODML are shown in Figure 36. These data were calculated using the mathematical models described in this report, and illustrate the differences in power requirements for achieving the two objectives. The power required for achieving odor control is the energy required to drive the rotor to supply the oxygen needed to meet the carbonaceous oxygen demand. The power requirements for achieving nitrogen control are higher as more oxygen input is necessary to oxidize all NH_4^+ to nitrates.

These power requirements are the maximum needed to achieve the stated objectives at different solids concentrations. It is important to identify the few assumptions that were made to calculate the data presented in

Figure 36. It was assumed (i) that all the available ammoniacal nitrogen is oxidized to nitrates; (ii) that no losses of nitrogen due to ammonia desorption occur during stabilization; and (iii) that no losses due to denitrification occur and a residual dissolved oxygen concentration of 2 mg/l is always maintained in the system. If these assumptions are not valid, then the estimates will differ.

During the oxidation of NH_4^+ to NO_2^-, hydrogen ions are generated, and as a result, the pH value of the system decreases (Equation 1). The pH value of the nitrifying stabilization system is generally near 7.0 or even slightly below 7.0. Under these conditions, nitrogen losses due to ammonia desorption become insignificant. In a non-nitrifying system, significant losses of nitrogen due to ammonia volatilization occur and it is very difficult to control such losses.

When the oxygen input to the stabilization system is stopped, denitrification of the oxidized forms of nitrogen occur. Even though the actual reactions involved are complicated, they can be summarized by:

$$2\,NO_3^- + 10H^+ \longrightarrow N_2\uparrow + 4H_2O + 2OH^- \quad (18)$$

$$2\,NO_2^- + 6H^+ \longrightarrow N_2\uparrow + 2H_2O + 2OH^- \quad (19)$$

The reaction is carried out by faculative heterotrophic organisms which use the nitrate and nitrite as electron acceptors and organic carbon as an energy source. The process of denitrification represents a further means of decreasing COD in the stabilization system.

One proposed means of establishing a nitrifying-denitrifying system is to cycle rotor operation on a regular and daily basis described in this report. Data indicate that nitrogen losses as high as 90% of the input could be achieved with this mode of rotor operation.

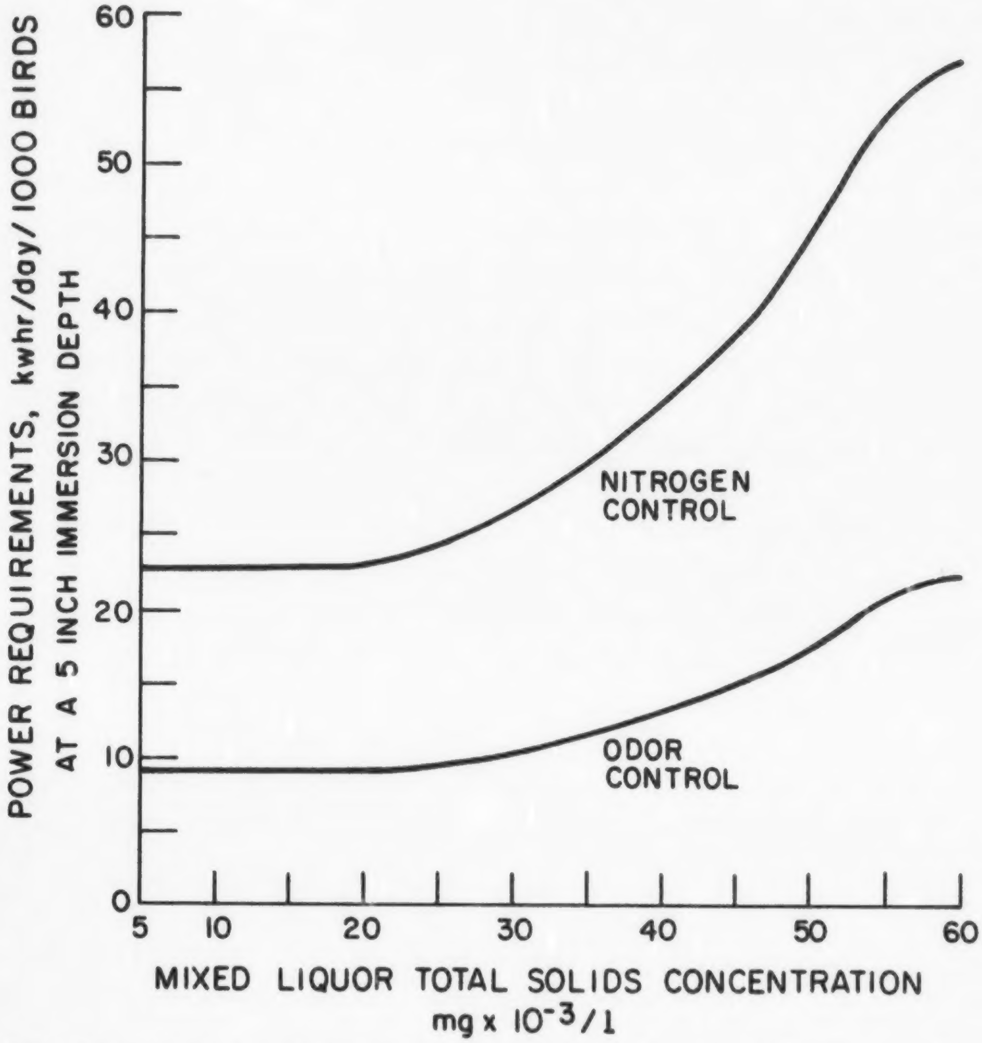

Figure 36. Quantitative effect of treatment objectives on aeration requirements.

A second method of establishing a nitrification-denitrification process in an oxidation ditch consists of sizing the oxygenation capacity so that conditions required for nitrification are achieved in a section of the ditch directly in front of the rotor, while anoxic conditions exist for some distance behind the rotor. Rotor aeration capacity must be designed within close tolerance in order for the system to operate effectively to remove nitrogen.

Cyclic rotor operation has been proposed in this model as the means of removing nitrogen. Sufficient oxygen is supplied by the rotor during the aeration period to achieve the required conditions for nitrification throughout the channel. Denitrification occurs during that part of the day when the rotor is not operating. This mode of operation for nitrogen removal allows for system flexibility. The aeration cycle may be altered to accommodate changes in treatment efficiency or waste loadings while at the same time maintaining the treatment objectives.

The data obtained in the studies on sequential rotor operation are shown in Figure 37. The maximum quantity of total nitrogen which could be removed from poultry excreta was 90% of the input nitrogen. The maximum amount which could be conserved (no denitrification period) was 70% of the input nitrogen.

On the basis of this data the following mass balance equation was used to describe the total nitrogen concentration in the mixed liquor:

$$S_e = S_o\ (.7 - kt) \text{ for } 0 < t < 12 \qquad (20)$$

where S_e = mixed liquor total nitrogen concentration, (mass/volume);

S_o = total nitrogen added to the ditch, (mass/day);

k = denitrification rate constant, (hour^{-1});

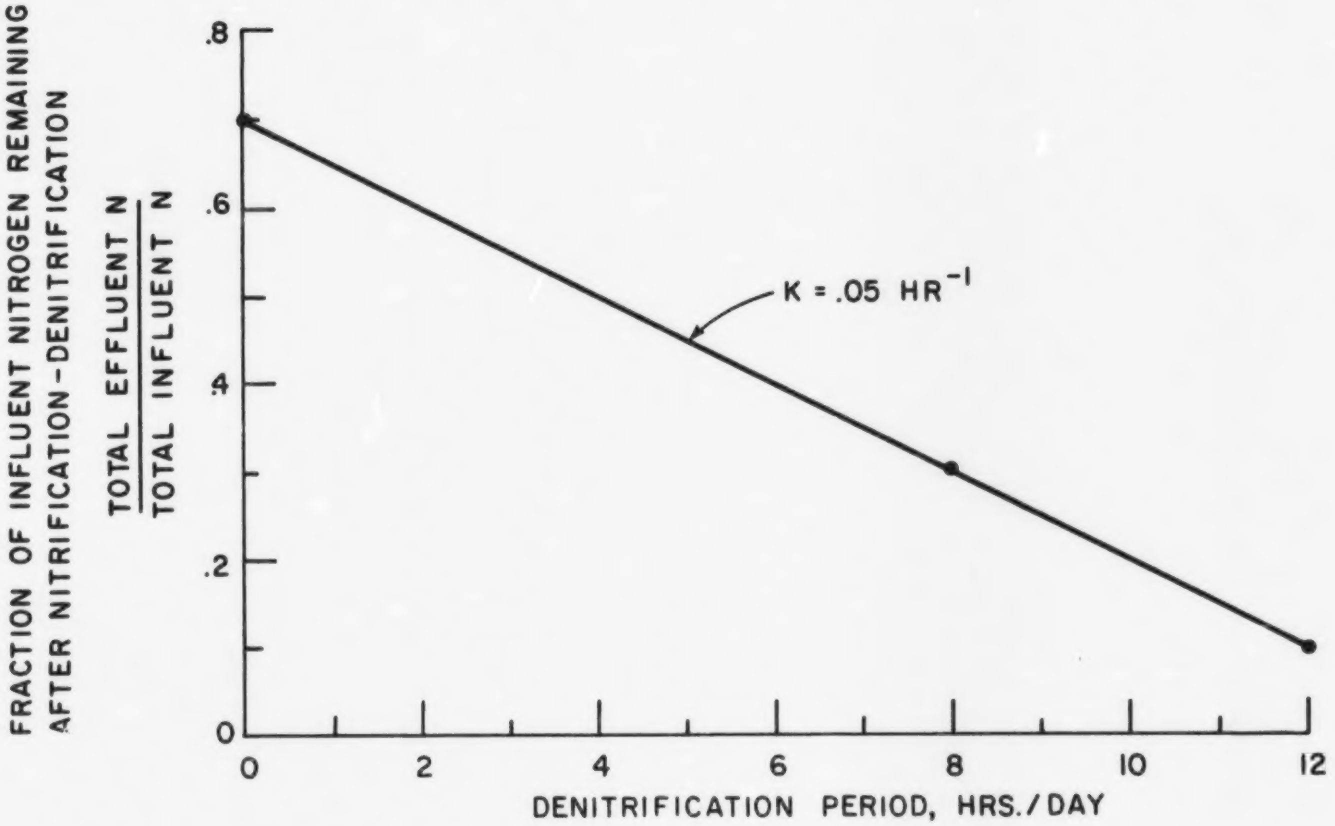

Figure 37. Nitrification-denitrification of cyclic rotor operation. (Prakasam et al., 1974).

t = length of the denitrification period, (hours/day).

The coefficient 0.7 in the equation signifies the fraction of nitrogen that can be conserved under no denitrifying conditions.

When using this process as a means of nitrogen removal, the aeration period will be reduced depending on the extent desired. As a result, Equation (17) must be modified to reflect the increased oxygen uptake rate. The following equation is used in the model to express oxygen demand for a nitrification system:

$$R_{N-D} = n\,(f_c \cdot S + 4.57\, f_N S_N) - \text{oxygen demand potentially available from } (NO_3 + NO_2) \text{ for denitrification}$$

$$= n(f_c \cdot S + 4.57\, f_N S_N) - (3.7\, NO_3\text{-}N + 2.3\, NO_2\text{-}N)k \cdot t \qquad (21)$$

where R_{N-D} = microbial oxygen demand for nitrification-denitrification system of the type described (mass/time);

t = length of the denitrification period (hours/day).

If the treatment objective is nitrogen conservation rather than removal, Equations 21 and 22 are applied in the model for conditions in which there is not a denitrification period. As discussed earlier and demonstrated in Equation 20, a maximum of 70% of the influent nitrogen was able to be conserved in the preliminary experimental studies.

Rotor Size

In the cyclic rotor operation described above, as the aeration period, t_a, decreases in order to increase the extent of nitrogen loss due to denitrification, the rate at which oxygen must be supported to the mixed liquor increases. The length of rotor required appears to be proportional to the oxygen demand. The relationship between nitrogen removal and the lengths of rotor needed to achieve these removals are shown in Figure 38. Ninety percent removal of nitrogen as observed in our studies correspond to 12 hours of rotor operation per day, and 30 percent removal corresponds to 24 hour operation of the rotor. It must be noted that these are based on limited experience with the different modes of operation of the oxidation ditch.

COSTS OF OPERATION IN FULL SCALE SYSTEMS

The feasibility of installing and operating waste stabilization systems in oxidation ditches are largely dependent on costs.

Houghton Farm Operations

Some details of the capital and operating costs of the Houghton Farm operation are given in Table 26. It can be noted that these cost estimates do not include maintenance or interest charges. Certain trade-offs in the total waste management system have not been considered. Before the installation of the oxidation ditch system, it was necessary to plow the soil following manure spreading to minimize the objectionable odors. Such plowing is no longer necessary resulting in a deletion of these costs. Costs associated with disposal have not been included in the estimates. The estimates presented in Table 26 are intended only to indicate that the economic impact of the installation of the oxidation ditch system is reasonable.

Manorcrest Farms Operations

The operating costs are dependent upon the efficiency of the aeration systems. The cage and the brush type rotors require the use of 5 and 2 HP motors,

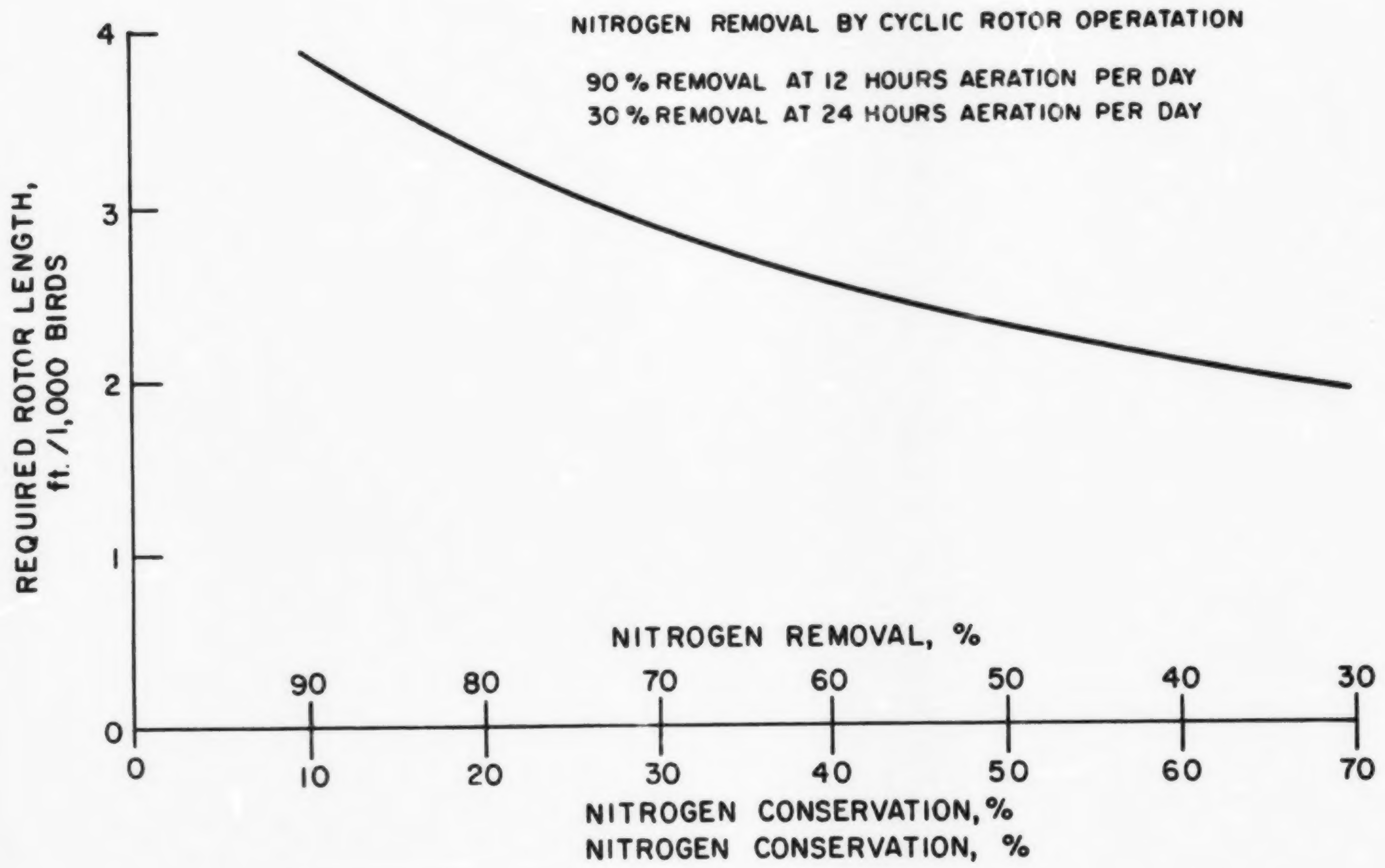

Figure 38. Relationship between nitrogen removal and rotor design requirements.

Table 26. CAPITAL AND OPERATING COSTS FOR OXIDATION DITCHES AT THE HOUGHTON POULTRY FARM

	Cost ($)	Depreciation (percent per year)	Cost per dozen eggs (¢)
Oxidation ditch (cost of construction)	$2800	10	0.093
Rotors	6116	10	0.204
Motors	1084	20	0.072
Power (@ 2.17¢ per KWH)			1.010
Total cost per dozen eggs based on estimated production of 300,000 dozen eggs per year			1.379

respectively. Comparing the cost of the two systems shows that with proper design of aeration equipment, the operating costs may be reduced (Table 27).

Mink Farm Oxidation Ditch System

From an economic standpoint, the operating cost of the JAM system, in terms of energy consumption, is comparable to that of the cage rotor. The JAM system has the flexibility of being able to be installed in phases to meet the desired degree of stabilization. The total electric power need for the JAM system for the 300 day period was 8010 kilowatt hours. Assuming a value of 2¢ per KWH, the operating cost was estimated to be 0.6¢ per mink per day. The design considerations were based on oxygen requirements only. The amount of oxygen transferred by the aerator was at least 7.5 times more oxygen than required on the basis of oxygen uptake by microorganisms in the wastewater. The power cost estimates of a better design treatment system may be only ten percent of the present operating cost of 0.6¢ per mink per day.

LAND APPLICATION OF POULTRY WASTE

Land disposal will continue to be the main method for disposing of poultry manure. Effective treatments have been developed, including the oxidation ditch method, for minimizing odors. As a result of treatment, the kinds and amounts of nitrogen compounds in the manure are altered. One of the objectives of this study was to determine if treated manure could still serve as a satisfactory source of N for plant uptake. An attempt was also made to evaluate the effect of manures on the environment when these manures were used as a source of N for plant growth.

Table 27. OXYGEN REQUIREMENT, POWER AND COST DATA FOR THE OXIDATION DITCH SYSTEMS AT MANORCREST FARMS, INC., CAMILLUS, NEW YORK

Parameter	Cage Rotor	Brush Rotor
Oxygen requirement (lb/hr/1000 birds)	4	4
Efficiency of equipment in tap water (lb/ O_2 per KWH)	2.1	2.16
Immersion depth (inches)	5	6
Rotor speed (RPM)	100	252
Power required (kilowatts)	1.9	1.85
Power supplied (KWH per hr)	3.50	1.50
Cost (¢ per bird per day)*	0.04	0.02

*Power cost is assumed to be 2¢ per KWH

Oxidation ditch stabilized manure was found to be as effective as fresh manure when used as a source of N for plant growth. Treatments such as the oxidation ditch did not reduce the effectiveness of N for plant growth.

It was also determined that nitrogen from the two manure sources applied at rates recommended for corn or grass production did not cause detrimental levels of nitrates in surface runoff from soils. Differences in runoff or soil loss could not be attributed to the source of manure.

It was noted in these investigations that soil nitrate levels under grass were lower than those under corn. This indicates that actively growing grasses are heavy feeders on nitrates in soil. On the other hand, nitrate levels are highest in corn soils in June indicating that rapid mineralization of N from manure is taking place but the corn plant, at the early stage of growth, does not have the capacity for a large uptake of N. These considerations must be taken into account when planning manure management systems.

Residual effects from poultry manure are rather small in terms of corn response when manure has been applied to supply up to 448 kg N/ha. Weather conditions can affect this as they influence soil moisture and soil temperature. About 50 percent of the total N in manure was mineralized in the first year as measured by corn and grass response. A much smaller percentage of the remaining N is mineralized in subsequent years (20).

SUMMARY

In conclusion, it can be stated that the studies described in this report indicate that it is possible to achieve the objectives of odor and nitrogen control. Several approaches have been presented for nitrogen control in poultry wastes with the aid of an oxidation ditch. Either conservation of nitrogen or its removal can be accomplished by operating the oxidation ditch under appropriate and controlled conditions described in this report. The results of this study indicated that up to 70% of the input nitrogen to the oxidation ditch can be conserved and up to 90% of it can be removed depending on the mode of operation chosen. Treated and untreated poultry manure are good sources of N for plant growth. Corn yields fertilized with about 200-400 kg N/ha compared favorably with corn yields from commercial fertilizer N. Subsoil nitrate levels were less than surface soil levels indicating most of the nitrates had not moved below the 23 cm depth. Runoff losses of nitrates and phosphates from manure were not affected by manure sources. The study also indicated that other environmental objectives such as waste stabilization and odor control need not be sacrificed when controlling nutrients.

SECTION VII

DESIGN EXAMPLES

The following design procedure summarizes the discussion of the model (28) for the design of an oxidation ditch continuous flow treatment system for livestock wastes. It delineates those parameters which need to be determined before the mathematical model can be used to establish design and operating parameters and outlines the relevant parameters. The first decision involves defining treatment objectives. In the design procedure this is assumed to be a prior management decision.

DESIGN PROCEDURE

1) Determine raw waste characteristics on a per animal per day basis- total solids, total COD, total Kjeldahl nitrogen, volume.

2) Determine treatability of the wastes, i.e., how much COD and how much total nitrogen can be removed through extended aeration. Determine the empirical solids removal rate from aeration studies.

3) Determine the number of animals above the ditch.

4) Calculate the ditch surface area required to collect the wastes from these animals. Allow for a two to three foot median strip along the center of the ditch.

5) Using a design liquid depth approximately three to four times the manufacturer's maximum recommended rotor immersion depth, calculate a tentative design volume. This will then be the maximum allowable volume. The rotor mixing requirements are directly proportional to the liquid depth. The final liquid depth should, if possible, be one that will not make design requirements for mixing higher than the rotor requirements for oxygenation as specified by the treatment objective.

6) If possible, design the system to operate with a mixed liquor total solids concentration of 20,000 mg/l or less.

7) If the treatment objective is nitrogen removal, use Figure 38 to determine the design length of the denitrification period.

8) Determine oxygenation and pumping characteristics of the rotor under standard conditions. Rotor power consumption data will also be useful to estimate operating costs.

9) The above data are then used to calculate the rotor design requirements for mixing and oxygenation, the solids retention time, volume of make-up water which must be added to maintain the constant volume and the mixed liquor total nitrogen concentration. The computer program used is illustrated in Appendix B.

10) Determine quantities of nitrogen which can be spread on available land by multiplying

   a) available bare ground area for spring or summer spreading x 224 kg/ha N
   b) available grass meadow acreage for spring, summer or fall spreading x 170 kg/ha N

c) available grass meadow acreage to be plowed for corn the following spring which can be spread in the previous spring, summer or fall x 224 kg/ha N.

DESIGN EXAMPLE

An egg producer, located in close proximity to suburban housing, has a poultry confinement unit with a total of 8,000 caged layers. He owns sufficient land to grow his own feed and since nitrogen fertilizers are in short supply, he would like to use the waste as a crop nutrient. Since he is located near the suburban development, he is forced to control the foul odors which have been coming from the confinement unit. On the basis of preliminary investigation of alternatives, the farmer has decided to install an oxidation ditch since it will be the most feasible means of achieving his objectives. He would like to know how to design and operate the system.

The hens are housed in four long rows with stairstep cage arrangements. There are 2000 hens in each row. In order to eliminate the need for a separate collection and handling system, two oxidation ditches will be built. Each ditch will collect the wastes from two rows of cages and a three-foot wide median strip in each ditch is to be used as a walkway.

The treatment objectives are: a) odor control, and b) maximum nitrogen conservation. Since the quantity of oxygen needed to conserve the nitrogen is larger than the quantity necessary to control odors, both treatment objectives will be met if the system is designed for maximum nitrogen conservation.

A laboratory analysis of the raw waste indicates the following characteristics:

Total Solids = 30,000 mg/bird-day
Total COD = 20,805 mg/bird-day
Total Kjeldahl nitrogen = 2,505 mg/bird-day
Volume = .118 liters/bird-day

In order for the wastes to fall directly into each ditch, a ditch length of 152 feet and a channel width of six feet is needed. The design surface area will be 2244 ft^2.

The farmer has decided to purchase Thrive rotors to supply aeration and mixing requirements in each ditch. The oxygenation and mixing capacities of the rotor have been previously determined and are available. The manufacturer's maximum recommended rotor immersion depth is six inches. Since mixing is hampered at liquid depths greater than three to four times the immersion depth, the liquid depth cannot be greater than 24 inches. A liquid depth of 20 inches is chosen. The ditch liquid volume will be 2740 ft^3 (106,000 liters) as designed. In addition to the liquid depth, the ditch should be constructed to provide a one foot freeboard clearance.

Since oxygen transfer efficiency of the rotor is greatest at a mixed liquor total solids concentration at or near 20,000 mg/l, each ditch will be designed to operate at a solids concentration of 20,000 mg/l.

Since the treatment objective is maximum nitrogen conservation, the system will be designed for 24 hour rotor operation.

The value of f_c, f_N, and K_s, which describe the aerobic treatment of caged layer poultry wastes have already been indicated and they may be used to calculate rotor design parameters for this problem. Because of the inaccuracy in predicting K_s, the solids retention time, mixed liquor total nitrogen concentration, and the rate at which make-up water must be added will not reflect actual design conditions. The model predicted design values of these variables are included in this problem for illustrative purposes only.

The computer program is used to calculate the magnitudes of the remaining design variables. The following is a list of the magnitudes of the control and model predicted design data:

Number of hens over each ditch = 4,000

Total channel length = 374 feet

Channel depth = 2.7 feet (20 inches + 1 foot freeboard)

Liquid depth = 20 inches

Liquid volume = 106,000 liters

Mixed liquor total solids concentration = 20,000 mg/l

Rotor immersion depth = 6 inches

Minimum length of rotor required = larger of rotor length required for mixing and rotor length required for oxygenation
= 6.8 feet

Solids retention times = 62 days

Mixed liquor total nitrogen concentration = 4,093 mg/l as N

Make-up water to be added = 1,242 liters/day plus the amount required to replace evaporation losses

Rotor power consumption = 95 kwhr/day (for 6.8 ft of rotor)

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SECTION IX

APPENDIX

```
      REAL POWER(12), O2CAP(12)
4     FORMAT(5X,I4,9F10.1)
5     FORMAT(' ','IMMERSION DEPTH TOO HIGH')
6     FORMAT(' ', 3F10.1)
      READ, CS, PRESS
C  INPUT RAW WASTE CHARACTERISTICS, CHANNEL CHARACTERISTICS,
C  TREATABILITY DATA, AERATOR OXYGENATION AND POWER DATA
      READ, WTS, TCOD, TKN, RWVOL, FN, FCOD
      READ, AREA, WIDTH, N
      READ, HENS, VOL, EFFTS, TIME
      READ, (O2CAP(I), I=1,N)
      READ, (POWER(I), I=1,N)
      DTS= EFFTS * VOL/10**6
      COD= TCOD * HENS/10**6
      TSIN= WTS*HENS
      VSS= .2 * DTS
C  CALCULATION OF SOLIDS REMOVAL RATE CONSTANT
      XK= .011 + .15*(COD/VSS)
C  CALCULATION OF MIXED LIQUOR SOLIDS RETENTION TIME
      HRT= EFFTS*VOL/ (TSIN-XK*EFFTS*VOL)
C  VOLUME OF MIXED LIQUOR WASTED DAILY
      FLOW= VOL/HRT
C  VOLUME OF MAKE-UP WATER REQUIRED
      WATER= FLOW-(RWVOL*HENS)
      DEPTH= VOL * .03531/AREA
C  DETERMINATION OF DESIGN PARAMETERS FOR MIXING, ODOUR
C  CONTROL AND NITROGEN CONTROL AT EACH IMMERSION DEPTH
      DO 50  I=1,N
      IF (N/12 .GE. DEPTH) GO TO 40
      CALL PUMP(DEPTH,VOL,AREA,I,XAREA,WIDTH,PCAP,Y,RFT1)
      CALL ODOR(TBOD,COD,HENS,DTS,ALPHA,BETA,CL,O2CAP,CS,
     1PRESS,HRBOD,RFT2,TRANS,EFFTS,I,FCOD)
      CALL NIT(FN,TOD,TCOD,TKN,HENS,RATE,TIME,CL,CS,TRAN2,
     1O2CAP,ALPHA,BETA,PRESS,RFT3,XKN,DENIT,FTKN,EFFTS,I,
     1FLOW,FCOD)
C  CALCULATION OF ENERGY REQUIREMENTS FOR MIXING, ODOUR
C  CONTROL AND NITROGEN CONTROL
      POW1= RFT1 * POWER(I) * TIME
      POW2= RFT2 * POWER(I)  * TIME
      POW3= RFT3 * POWER(I) * TIME
      PRINT 4, I,RFT1,RFT2,RFT3,POW1,POW2,POW3,HRT,FTKN,
     1WATER
      PRINT 6, VOL, EFFTS, TIME
      GO TO 50
40    PRINT 5
50    CONTINUE
      STOP
      END
```

```
C   SUBROUTINE FOR CALCULATING MIXING REQUIREMENTS
       SUBROUTINE PUMP(DEPTH,VOL,AREA,I,XAREA,WIDTH,PCAP,Y,
     C      RFT1)
C   CROSS-SECTIONAL AREA OF CHANNEL
       XAREA= WIDTH * DEPTH
C   REQUIRED PUMPING CAPACITY AND ROTOR LENGTH
       PCAP= XAREA * 1.8
       Y= .575 * I
       RFT1= PCAP/Y
       RETURN
       END


C   SUBROUTINE FOR CALCULATING AERATION REQUIREMENTS FOR
C   ODOUR CONTROL
       SUBROUTINE ODOR(TBOD,COD,HENS,DTS,ALPHA,BETA,CL,O2CAP,
      1CS,PRESS,HRBOD,RFT2,TRANS,EFFTS,I,FCOD)
       REAL O2CAP(12)
C   CARBONACEOUS OXYGEN DEMAND
       TBOD= FCOD * COD* 10**3
C   CALCULATION OF ALPHA
       IF(EFFTS .LE. 20000.) GO TO 5
       IF (EFFTS .LE. 55000.) GO TO 6
       ALPHA= .4
       GO TO 7
5      ALPHA= 1.
       GO TO 7
6      ALPHA= -.17 * EFFTS/ 10**4 + 1.36
7      BETA= 1.
       CL= 0.
C   OXYGEN TRANSFER CAPACITY OF ROTOR
       TRANS= O2CAP(I)*ALPHA*((BETA*CS-CL)/CS)*PRESS/14.7
C   AVERAGE STEADY STATE OXYGEN UPTAKE RATE
       HRBOD= TBOD/24.
C   REQUIRED ROTOR LENGTH FOR ODOUR CONTROL
       RFT2= HRBOD/TRANS
       RETURN
       END


C   SUBROUTINE FOR CALCULATING AERATION REQUIREMENTS FOR
C   NITROGEN CONTROL
       SUBROUTINE NIT(FN,TOD,TCOD,TKN,HENS,RATE,TIME,CL,CS,
      1TRAN2,O2CAP,ALPHA,BETA,PRESS,RFT3,XKN,DENIT,FTKN,
      1EFFTS,I,FLOW,FCOD)
       REAL O2CAP(12)
C   CARBONACEOUS AND NITROGENOUS OXYGEN DEMAND
       TOD= (FCOD*TCOD + 4.57*FN*TKN)*HENS/10**3
C   AVERAGE STEADY STATE OXYGEN UPTAKE RATE
       RATE= TOD/TIME
C   CALCULATION OF ALPHA
       IF (EFFTS .LE. 20000.) GO TO 5
      IF (EFFTS .LE. 55000.) GO TO 6
      ALPHA= .4
      GO TO 7
5     ALPHA= 1.
      GO TO 7
6     ALPHA= -.17 * EFFTS/ 10**4 + 1.36
7     BETA= 1.
      CL= 2.
C  OXYGEN TRANSFER CAPACITY
      TRAN2= O2CAP(I)*ALPHA*((BETA*CS-CL)/CS)*PRESS/14.7
C  ROTOR LENGTH REQUIRED FOR NITROGEN CONTROL
      RFT3= RATE/TRAN2
C  MIXED LIQUOR TOTAL NITRCGEN CONCENTRATION
      XKN=    .05
      DENIT= 24. - TIME
      FTKN= HENS*TKN*(.7-XKN*DENIT)/FLOW
      RETURN
      END
```

Nomenclature

ALPHA = ratio of K_La in the mixed liquor to K_La in water.
AREA = surface area of the channel, (ft^2).
BETA = ratio of dissolved oxygen concentration at saturation for wastewater to that of pure water.
CL = mixed liquor residual DO, (mg/l).
COD = total COD in mixed liquor, (kg).
CS = oxygen saturation concentration, (mg/l).
DENIT = length of the denitrification period, (hr/day).
DEPTH = liquid depth, (ft).
DTS = weight of total solids in mixed liquor, (kg).
EFFTS = mixed liquor total solids concentration, (mg/l).
FCOD = fraction of raw waste COD oxidized.
FLOW = rate of mixed liquor removal for disposal, (l/day).
FN = fraction of raw waste TKN which is biodegradable.
FTKN = mixed liquor total nitrogen concentration, (mg/l).
HENS = number of birds above the ditch.
HRBOD = average oxygen utilization rate, (gm O_2/hr).
HRT = solids retention time, (days).
I = rotor immersion depth, (in).
N = maximum rotor immersion depth, (in.).
O2CAP = oxygenation capacity of rotor in water, (gm O_2/hr).
PCAP = rotor required pumping capacity, (ft^3/sec).
POWER = power consumption rate of rotor, (kw/ft of rotor).
POW1 = rotor power consumption for mixing, (kwhr/day).
POW2 = rotor power consumption for odor control, (kwhr/day).
POW3 = rotor power consumption for nitrogen control, (kwhr/day).
PRESS = atmospheric pressure, (lb/in^2).
RATE = microbial oxygen utilization rate, (gm O_2/hr).

RFT1 = rotor length required for pumping, (ft).

RFT2 = rotor length required for odor control, (ft).

RFT3 = rotor length required for nitrogen control, (ft).

RWVOL = volume of raw waste, (l/bird-day).

TBOD = microbial oxygen demand for odor control, (kg/day).

TCOD = total COD in raw waste, (mg/bird-day).

TIME = daily length of aeration period, (hr/day).

TKN = total Kjehldahl nitrogen in raw waste, (mg/bird-day).

TOD = carbonaceous and nitrogenous microbial oxygen demand, (gm O_2/day).

TRANS = rotor oxygen transfer capacity, (gm O_2/hr-ft of rotor).

TRAN2 = rotor oxygen transfer capacity, (gm O_2/hr-ft of rotor).

TSIN = total solids added daily through raw waste, (mg/day).

VOL = volume of the mixed liquor, (l).

VSS = total weight of mixed liquor volatile suspended solids in the ditch, (kg).

WATER = rate of addition of makeup water, (l/day).

WIDTH = width of the channel, (ft).

WTS = total solids in raw waste, (mg/bird-day).

XK = solids removal rate constant, (day^{-1}).

XKN = denitrification rate constant, (hr^{-1}).

XREA = liquid cross-sectional area, (ft^2).

Y = rotor pumping capacity, (ft^3/sec-ft of rotor).